LITERATURE SURVEY ON MATERIALS TO IMPROVE LOW TEMPERATURE FLUIDITY OF FOG OIL

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13. ABSTRACT (Maximum 200 words)

The liquid mineral oil used as fog oil in smoke generation becomes too viscous to meet the flow requirements of the M157, M1059, M56, and M58 smoke generator systems at low temperatures. Historically, diesel fuel has been added to the cold mineral oil as a flow enhancer, but this practice introduces an obscurant whose procurement specification does not contain the same controls as the fog oil specification. This study was conducted to identify commercial products with the potential to replace diesel fuel as a low temperature flow enhancer for mineral oil and to maintain the fog oil standard. Several flow enhancement candidates were identified, including a mineral oil and several synthetic products. The kinematic viscosities of these products remain low even at low temperatures, ranging from 8 to 90 cSt at -25°C (-13°F), compared to 2851 cSt at -25°C for mineral oil alone. The flow enhancers identified in this study could reduce the viscosity of mineral oil so that the blend would be pumpable at the lowest required operating temperature. The cost of each of flow enhancer exceeds that of mineral oil, but cost considerations must take into account the comparatively low usage rate of an extreme cold flow enhancer. Another consideration is the product's human toxicity. Most products identified for this study exhibit a low degree of toxicity as oils, but little is known about their potential toxicity as a fog.

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EXECUTIVE SUMMARY

Problems and Objectives: The mineral oil that is used as fog oil becomes too viscous to be pumped by smoke generators at low temperatures. Traditionally, the viscosity of the mineral oil has been reduced by the addition of diesel fuel during cold weather operations. However, a revision to MIL-L-12070D, "Fog Oil," has been drafted. This revision, known as MIL-PRF-12070E, contains new toxicology test and reporting requirements for fog oil. A blend of diesel fuel with mineral oil would not meet these requirements. If the revision to MIL-L-12070D is approved, a new material for fog oil will be needed. This material could be either a single-component fog oil for use at any temperature, or a substance to blend with the mineral oil used as fog oil to reduce its low temperature viscosity.

Importance of Project: This project will determine the availability of materials to replace diesel fuel as a component of fog oil at low temperatures. Such materials will be vital if the revision to MIL-L-12070D is approved.

Technical Approach: The main component of this project consisted of a literature search to identify types of potential products, and a series of conversations with manufacturers of different types of lubricants to identify specific products. A set of data was generated for each product, which consisted of information provided by the manufacturer or through laboratory testing.

Accomplishments: This project resulted in a set of data about commercial products that could be used as fog oil or as components of fog oil. Information related to predicted performance of the products as obscurants is provided, as well as a ranking of the products by cost and safety. The safety ranking includes shipping and handling considerations, human exposure effects, and environmental impact.

Military Impact: The results of this project show the possibility of eliminating diesel fuel as a component of fog oil blends at low temperatures.

FOREWARD

This work was performed by the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, and funded under Contract No. DAAK70-92-C-0059 for the period November 1997 through January 1998. Mr. T. Johnson (AMOPM-SM) served as the project technical monitor.

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1.0 BACKGROUND

Smoke screens have been used as obscurants for both defensive and offensive operations since World War I. The primary function of smoke is to enhance survivability by obscuring troops, troop movement, and equipment. Smoke generation has become an integral component of tactical response in battlefield situations.

Smoke is generated through the use of a mechanical smoke generator. Smoke Generator Fog Oil (or just "fog oil") is pumped into the smoke generator, where it is heated to vaporization and disseminated into the ambient air. The vapor cools as it enters the air, condensing into small droplets that scatter light and produce a visual screen.

Currently, fog oil consists of low-viscosity petroleum oil as defined by MIL-F-12070D (1)[1]. This mineral oil provides a suitable smoke screen at temperatures above -12°C (10°F). However, at lower temperatures the mineral oil thickens and becomes too viscous for the mechanical smoke generator to pump. Historically, diesel fuel has been added to the mineral oil during low-temperature usage to reduce the mineral oil's viscosity. However, toxicology studies in rats, mice, and guinea pigs have shown diesel fuel to be toxic when fumes that have been vaporized and then condensed were inhaled. These studies were conducted at high concentrations of diesel fumes and may not be representative of human exposure during use of diesel fuel blended with fog oil, but some health risk may be present. The release of diesel fuel into the air also introduces environmental issues.

A draft revision to the military specification that governs fog oil was created (2). This revision, MIL-PRF-12070E, contains additional test and reporting requirements that control toxicological risk. If the draft revision meets final approval, any fluid used in a smoke-generation system would have to comply with this standard, whether this fluid is mineral oil alone or a fog oil blend to be used at low temperatures when mineral oil itself will not flow. The new tests contained in MIL-PRF-12070E include tests of carcinogenicity, mutagenicity, and UV absorption (an indicator of polynuclear aromatic [PNA] content). Similar types of

[1] Underscored numbers in parentheses refer to the list of references at the end of this report.

tests have been performed on diesel fuel in previous research efforts (3). Due to the addition of these toxicology test requirements, it is believed that a blend of mineral oil with diesel fuel would not be able to meet the requirements of the proposed revision to the military specification.

An alternative to blending diesel fuel with mineral oil must be found in order to continue to operate smoke generators at temperatures below -12°C (10°F). This alternative could consist of a substance to be added to the existing mineral oil only during cold weather operations, an additive that would be added to all mineral oil, or a new oil (or other product) to replace the existing mineral oil. Based on the specifications of the pump, the product must have a viscosity no greater than 770 cSt at the lowest operating temperature of -40°C (-40°F). Products with viscosities ranging from 3.4 to 4.17 cSt at 100°C (212°F) as required in MIL-L-12070D must have a viscosity index between 138 and 176 and a pour point lower than -40°C (-40°F) to meet the low-temperature viscosity requirement. The mineral oil that is currently used as fog oil has a pour point of -40°C and a viscosity index of 16.

2.0 APPROACH

The goal of this project was to conduct a literature search to identify potential alternatives to the mineral oil/diesel fuel blend. Lubricant manufacturers were contacted, and their product lines were discussed. When a product with the potential to flow well at extremely low temperatures was identified, a set of data regarding that product's physical properties, toxicological history, and cost was assembled. Table 1 presents a listing of the products that were identified. More information on the manufacturers of the products is contained in Appendix A.

Table 1. Summary of Products Identified					
AL Code	I.D.	Manufacturer	Product Name	Product Type	Typical Application
AL-25243	MIN1	ALCO	Current Rev. D	Mineral Oil	Fog oil
AL-25241	MIN2	Pennzoil	Potential Rev. E	Mineral Oil	Fog oil
AL-25242	MIN3	U.K Fog Oil	Potential Rev. E	Mineral Oil	Fog oil
AL-25265	MIN4	Royal Lubricants	Royco 481	Mineral Oil w/add	Fog oil for airshows
AL-25248	MIN5	Witco	LP 100	Mineral Oil	
AL-25238	MIN6	Paratherm	NF	Mineral Oil	Heat transfer fluid
AL-25325	MIN7	Conoco	Industrial Oil 70	Mineral Oil	Lubricant base stock
AL-25246	SOL8	Exxon	Isopar M	Synthetic Isoparrafin	Solvent
AL-25247	SOL9	Exxon	Exxsol D-80	Mineral Oil	Solvent
AL-25249	SOL10	Lubriplate	Pure Flush	Mineral Oil	Flushing oil
AL-25239	PAO11	Amoco	Durasyn 162	Synthetic Polyalphaolefin	Base stock
AL-25256	PAO12	Amoco	Duarsyn 164	Synthetic PAO	Base stock
AL-25232	PAO13	CPI	CP-4614, 15-F	Synthetic PAO	Lubricant
AL-25233	PAO14	CPI	CP-4614, 5-F	Synthetic PAO	Lubricant
AL-25209	PAO15	Henkel	PAO4	Synthetic PAO	Lubricant base stock
AL-25257	EST16	Henkel	2911	Synthetic Ester	Lubricant base stock
AL-25258	EST17	Henkel	2958	Synthetic Ester	Lubricant base stock
AL-25327	EST18	Paratherm	NF/LV	Synthetic Ester	Heat transfer fluid
AL-25194	PPD19	RohMax	Acryloid 150	Methacrylate Copolymer	Pour point depressant

The search for products focused on four general types. The first type of product was highly refined mineral oils, similar to the current fog oil. Mineral oils can range from very light (and too volatile to be suitable as a fog oil) to very heavy (and much too viscous to be used as fog oil). Therefore, ISO Viscosity Grade 22 and low pour point mineral oil products were requested in order to identify suitable products offered by manufacturers. The mineral oil currently used as fog oil has an ISO Viscosity Grade of 22, or approximately 4 cSt (centistokes) at 100°C, a pour point of -40°C (-40°F), and a viscosity index of 16.

The second type of product was polyalphaolefins, or PAO. PAO is known to have boiling/vaporization properties similar to mineral oils, while exhibiting very good low-temperature performance and high viscosity indices. Other advantages of PAO include varying degrees of biodegradability, and low toxicity. The lubricants industry has developed a simple method of describing different grades of PAO. A product with a viscosity of approximately 2 cSt at 100°C is referred to as PAO2; if the 100°C viscosity is near 4 cSt, the product is called a PAO4, and so on. For this study, PAO4 and PAO2 were reviewed. PAO4 products would be similar in viscosity to an ISO Viscosity Grade 22 mineral oil such as fog oil. PAO2 products would be more similar to the diesel fuel that is currently used to cut the cold-temperature viscosity of fog oil.

Synthetic esters were the third type of product researched. Most of those that were found to have good low-temperature performance were diesters. Diesters have an even greater potential for low-temperature performance than PAO, as well as better biodegradability and even lower toxicity. They are also generally more expensive. Different types of diesters can be referred to by their 100°C viscosity, pour point, or another data point as determined by the intended application.

Pour point depressant additives were the fourth and final type of product evaluated. Very small quantities of a pour point depressant can be added to a mineral oil or other base stock to decrease its pour point as well as its low-temperature viscosity.

Absent from this list of products is any type of biogenic or vegetable-based product. This type of product was researched in the initial stages of this study. It was found that, in general, vegetable oils have much higher pour points than mineral oil products. Since the focus of this study was to identify products that would improve the low-temperature performance of fog oil, it was decided that vegetable oils would not be emphasized in this work.

The product labeled MIN1 is the mineral oil that is currently used as fog oil. Information about this product was provided to TFLRF by the American Lubricants Company (ALCO), which provides the fog oil to the military. Two of the products listed in Table 1, MIN2 and MIN3, were developed to meet the new toxicology requirements that are being drafted into the fog oil military specification. Information and samples of these products were provided to TFLRF by PM Smoke rather than directly from industry. MIN2 was developed by Pennzoil, and some testing of this oil's smoke generation properties has already been conducted. MIN3 was manufactured by Rhoden Limited in the United Kingdom.

It should be noted that the product labeled MIN4 is a formulated lubricant with a mineral oil base stock. In addition to mineral oil, this product contains a methacrylate copolymer pour point depressant in a 0.75% concentration, as well as butylated hydroxytoluene (BHT) as an antioxidant in a 1% concentration.

The gathered information was used to assess the products in three different categories, which are discussed in the following sections. Section 3 contains an assessment of the products' potential for performance as a fog oil based on low-temperature properties, distillation range, refractive index, and other indicators. A product risk assessment based on factors related to toxicology, safety of handling, and environmental impact is presented in Section 4. Section 5 contains a cost comparison of the products based on cost per drum and usage rate when blended with mineral oil. Conclusions and recommendations are presented in Section 6.

3.0 PERFORMANCE ASSESSMENT OF PRODUCTS

The performance of the different products can be divided into three areas: flow at low temperatures, effectiveness in smoke production, and ease of use. Each of these categories will be discussed separately.

3.1 Flow at Low Temperatures

Fog oil must have low enough viscosity at low temperatures for the smoke generator apparatus to be able to pump it. Specifications for the pump define the maximum allowable viscosity to be 770 cSt. Fog oil is used at temperatures as low as -32°C (-25°F); therefore, a fluid with a viscosity no greater than 770 cSt at -32°C is needed. MIL-L-12070D requires that the fog oil have a 100°C viscosity between 3.4 and 4.17 cSt. Typically, manufacturers know the viscosities of their products only at the relatively high temperatures of 40 and 100°C (104 and 212°F), but viscosity index can be used to predict a product's low-temperature viscosity from its high-temperature viscosity. A product with a low viscosity index will have a greater degree of viscosity increase at low temperatures than a product with a high viscosity index. A product that meets both the low and high temperature viscosity requirements must have viscosity index between 138 and 176. Therefore, information on products with very low pour points and high viscosity indices was solicited. Samples of the more promising products were requested and delivered to TFLRF (SwRI) for low-temperature kinematic viscosity testing. This data is presented in Table 2. Pour point testing was conducted according to ASTM D 97, "Pour Point of Petroleum Products". Viscosity testing was conducted according to ASTM D 445, "Kinematic Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity)". Viscosity indices were calculated according to ASTM D 2270, "Standard Practice for Calculating Viscosity Index From Kinematic Viscosity at 40 and 100°C."

Viscosity tests were not conducted on PPD19 because it is a pour point depressant intended for use only as an additive. Similarly, no viscosity index is reported for this product.

Table 2. Low-temperature Data

Product	Pour Point (°C)	Viscosity Index	K. Vis, -40°C (cSt)	K. Vis, -32°C (cSt)	K. Vis, -25°C (cSt)	K. Vis, 40°C (cSt)	K. Vis, 100°C (cSt)
Fluids that were highly viscous at low temperatures, similar to the current fog oil:							
MIN1	-40	16	30730		2851	21.3	3.69
MIN2	-47	34	34753		3180	18.7	3.5
MIN3	-15	44	Frozen		Frozen	15.6	3.2
MIN5	-40	23	45268		3695	20	3.6
MIN6	-43	123	36155		3199	16.8	3.76
Fluids that could be used instead of mineral oil:							
MIN4	-57	67	2700	847		10.5	2.6
MIN7	-46	115	5709	1109		11	2.9
PAO12	-68	124	2621		617	17	3.9
PAO15	-69	123	2441		582	16.9	3.9
Fluids that could be blended into mineral oil as flow enhancers:							
SOL10	-37	ND*	Frozen		361	7	1.8
PAO13	-72	120	2704		293	16.8	3.8
EST17	-72	138	1229		289	10.3	2.9
PAO11	-60	ND	296		91	5.54	1.9
PAO14	-69	ND	293	135	91	5.1	1.7
EST16	-72	ND	184		60	4.8	1.7
EST18	-68	ND	108	57			1.45
SOL8	-60	ND	59		21	2.41	1.01
SOL9	-51	ND	Frozen	9.8	8	1.71	1.01
PPD19	-18						

* ND = Not Defined. ASTM D 2270 states that the viscosity index is not defined and may not be reported for oils of kinematic viscosity less than 2.0 cSt at 100°C.

Several of the products in Table 2 were found to be too viscous to be used at extremely low temperatures. The viscosities of these products over a temperature range from –40 to 100°C (-40 to 212°F) are plotted in Figure 1. These products provide little or no low-temperature advantage over the mineral oil that is currently used as fog oil. The products in this category were all mineral oils and included the current fog oil, the samples of potential fog oils that were received from PM Smoke, and three samples received from commercial sources. The worst low-temperature performance was exhibited by MIN3, which was expected based on its high pour point.

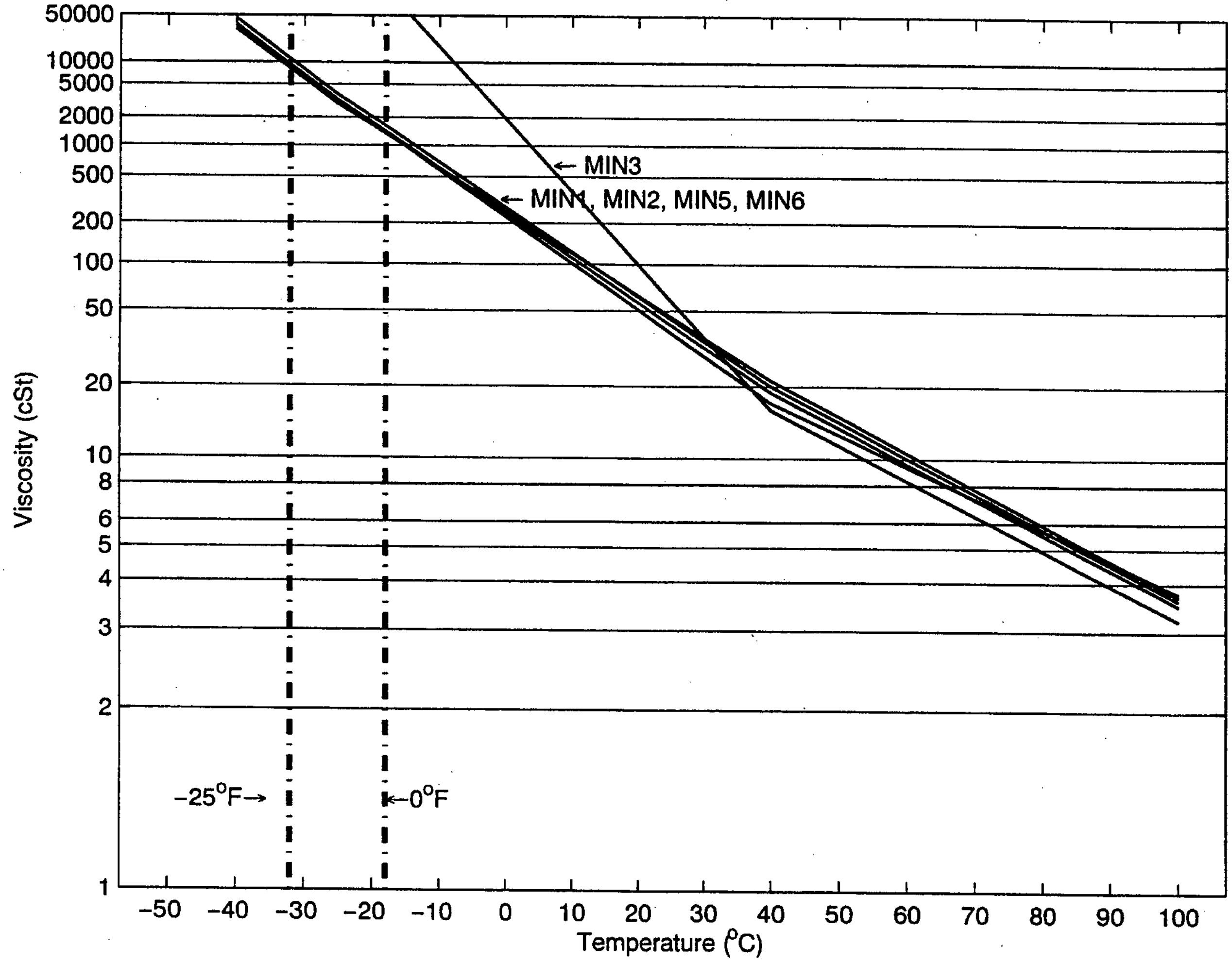

Figure 1. Viscosity Curves—Products With Poor Flow at Low Temperatures

A few products that could be used instead of mineral oil, and that would not require any flow enhancement at low temperatures, were identified. One of these products, MIN4, is a mineral oil with a pour point depressant. MIN7 is a mineral oil with no additives. The other two products are synthetic polyalphaolefins. The viscosities of these products are plotted in Figure 2.

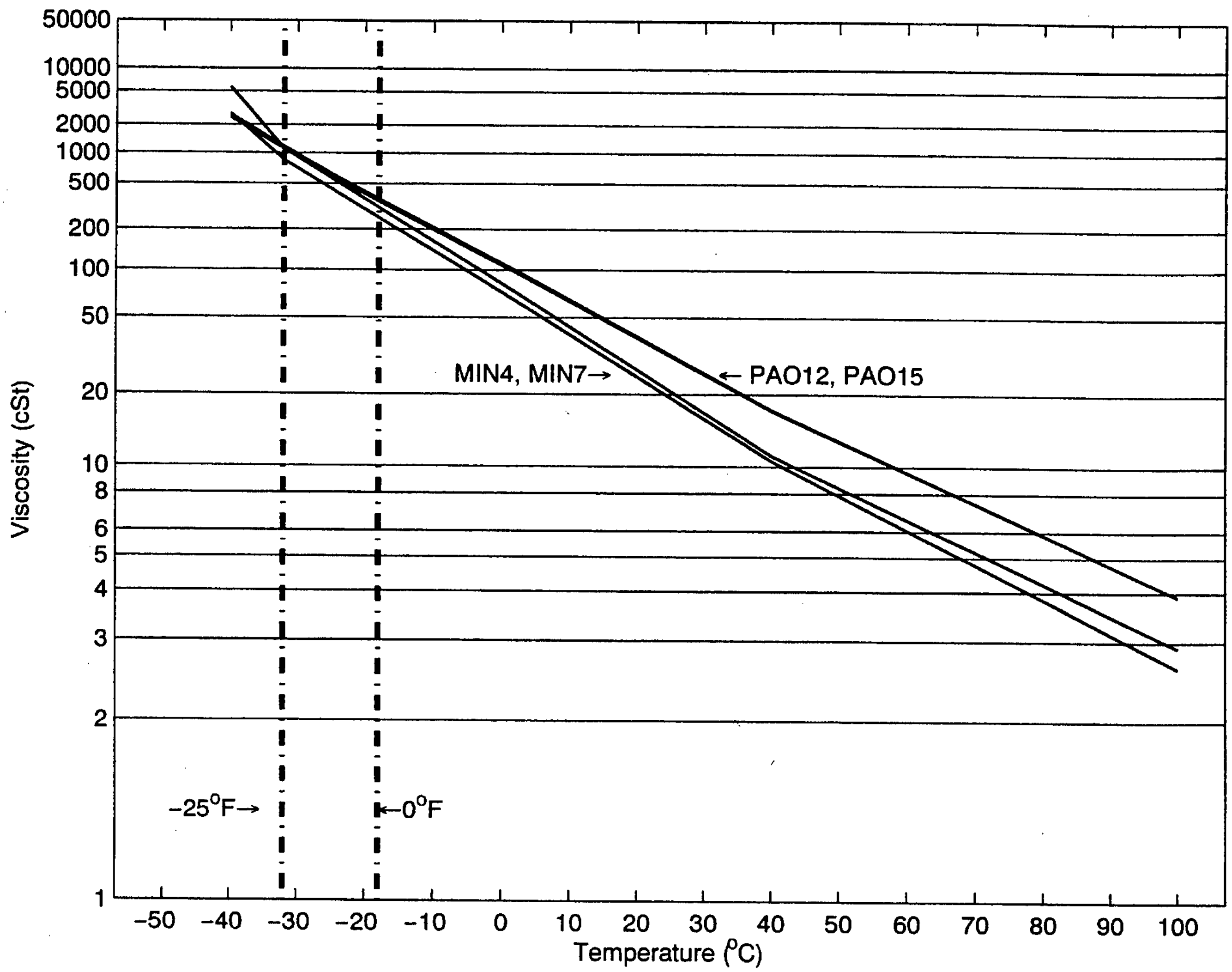

Figure 2. <u>Viscosity Curves—Products That Could Be Used As Fog Oil Without Blending</u>

A number of "flow enhancement" products that had very low viscosities, and could be blended with thicker mineral oil to reduce viscosity or enhance flow, were identified. This category includes most of the synthetic esters and polyalphaolefins that were identified. Also included are the three mineral oil solvents. The viscosities of these products are plotted in Figure 3.

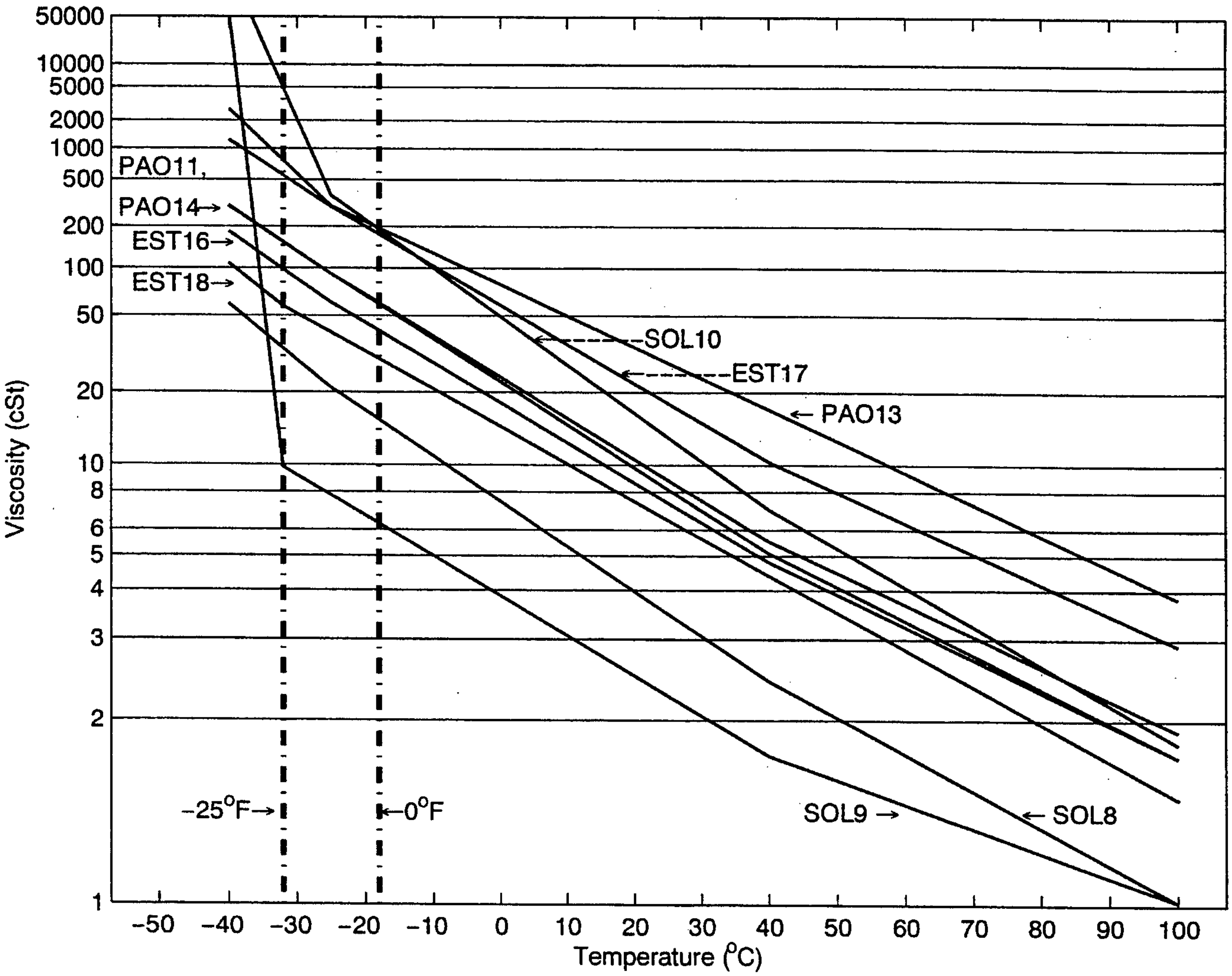

Figure 3. **Viscosity Curves—Products That Could Be Used To Enhance Flow of Fog Oil**

Further low-temperature viscosity tests were conducted on blends of mineral oil and possible flow enhancement products. The flow enhancers that were used in the blends were EST16, PAO11, and SOL8. The pour point depressant PPD19 was also blended into mineral oils. The mineral oils that were used in the blends were MIN1 (the current fog oil) and MIN2 and MIN3 (the fog oils received from PM Smoke). Table 3 shows the blend ratios that reduced the viscosity of the mineral oils to around 770 cSt. Also included in that table are the estimated blend ratios of the other flow enhancers that were not tested. These ratios were developed based on viscosity similarity to the products tested in order to provide an idea of the usage rate for those products. A specific viscosity resulting from the blend is shown only for those blends that were tested; viscosity is listed as "N/T" (Not Tested) for the blends that were estimated.

Table 3. Low-temperature Testing of Blends

Products in Blend		-32°C		-18°C	
Flow Enhancer	Mineral Oil	Flow Enhancer: Mineral Oil	Viscosity (cSt)	Flow Enhancer: Mineral Oil	Viscosity (cSt)
PAO11	MIN1	40:60	773	10:90	626
PAO11	MIN2	40:60	771	10:90	N/T
PAO11	MIN3	60:40	507	10:90	316
SOL8	MIN1	30:70	810	10:90	564
SOL8	MIN2	30:70	698	10:90	N/T
SOL8	MIN3	50:50	421	10:90	N/T
EST16	MIN1	30:70	899	10:90	575
EST16	MIN2	30:70	863	10:90	N/T
EST16	MIN3	60:40	298	10:90	N/T
PPD19	MIN1	0.25:99.75	~2000	0.25:99.75	N/T
PPD19	MIN2	0.25:99.75	>2000	0.25:99.75	N/T
PPD19	MIN3	0.25:99.75	>2000	0.25:99.75	N/T
SOL9	MIN1	20:80	N/T *	5:90	N/T
PAO14	MIN1	40:60	N/T	10:90	N/T
EST18	MIN1	30:70	N/T	10:90	N/T
PAO13	MIN1	90:10	N/T	50:50	N/T
EST17	MIN1	90:10	N/T	50:50	N/T

* N/T = Not Tested. This blend ratio is an estimation, and it's viscosity was not tested.

The product PPD19 is a pour point depressant and would be blended into the mineral oil in very small quantities. The blend listed in the table above was based on an estimate from the manufacturer of the pour point depressant; if that blend were optimized, it is likely that the viscosity could be reduced further. The manufacturer of the product indicated willingness to assist in the optimization process.

Four of the blends included in Table 3 were selected for additional testing to determine the effects of adding the flow enhancer on some of the other properties of mineral oil. These blends were identified in Table 4.

Table 4. Blends of Flow Enhancers with Mineral Oils

AL Code	I.D.	Flow Enhancer	Mineral Oil	Flow Enhancer: Mineral Oil
AL-25286	BL20	SOL8	MIN1	30:70
AL-25287	BL21	EST16	MIN1	30:70
AL-25288	BL22	PAO11	MIN1	40:60
AL-25255	BL23	PPD19	MIN1	0.25:99.75

Tests of pour point and viscosity were conducted on these fluids at a range of temperatures from –25 to 100°C. The results are shown in Table 5 and in Figure 4.

Table 5. Low-temperature Data for Blends

Product	Pour Point (°C)	Viscosity Index	K. Vis, -32°C (cSt)	K. Vis, -25°C (cSt)	K. Vis, 40°C (cSt)	K. Vis, 100°C (cSt)
BL20	<-66	54	698		8.9	2.3
BL21	<-66	91	863		10.5	2.7
BL22	<-66	78	771		10.2	2.6
BL23	-33	105		1496	15.7	3.55

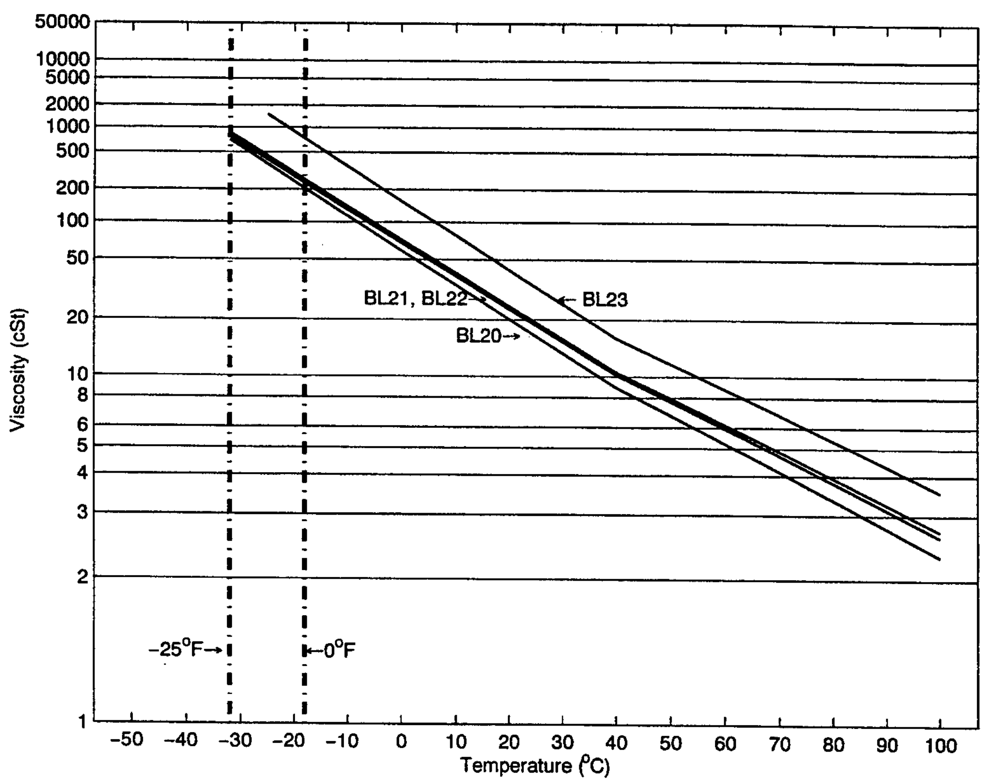

Figure 4. Viscosity Curves—Blends of Flow Enhancers with the Current Fog Oil

3.2 Smoke Production

No single property has been identified that can accurately predict a fluid's performance in smoke generation. However, some properties have been identified that can be combined to provide a general indication of a fluid's potential to make smoke. The boiling range is informative because it has been found that heavy molecular compounds (high boiling range) make a better smoke screen than light molecular compounds (low boiling range). However, the final boiling point of the product must be below the operating temperature of the smoke generator (550°C / 1000°F), or the heaviest portion of the fog oil will remain as residue and will not convert to smoke. Refractive index is an indication of the amount of change in the direction of light passing through a fluid; in the case of smoke, more refraction is better. A low vapor pressure is desirable, so that once the fluid has been converted to smoke, it will remain a visible smoke rather than quickly evaporate. Data on these indicators is presented in Table 6, which includes each of the products that were listed in Table 1 as well as the blends that were presented in Table 4. The boiling range was tested according to ASTM D 2887, "Boiling Range Distribution of Petroleum Fractions by Gas Chromatography." Refractive index was tested under ASTM D 1218, "Refractive Index and Refractive Dispersion of Hydrocarbon Liquids." Vapor pressure was not tested during this study; this data is presented in Table 6 only if the information was available from the manufacturer.

It should be noted that boiling range results are somewhat dependent on the judgement of the test operator. Appendix B contains further details of this test method as well as the raw data that was reduced for presentation in Table 6.

Product	Boiling Range		Refractive Index	Vapor Pressure (mm Hg)
	Initial Boiling Point (°C)	Final Boiling Point (°C)		
MIN1	232	475	1.4822	<0.1
MIN2	264	444	1.4830	
MIN3	282	514	1.4668	
MIN4	215	450	1.4804	<0.5
MIN5	228	541	1.4783	<0.005
MIN6	201	525	1.4768	<1
MIN7*				nil
SOL8	189	294	1.4362	<0.1
SOL9	181	266	1.4378	0.2
SOL10	163	565	1.4577	<0.01
PAO11	249	430	1.4450	<1
PAO12	316	531	1.4554	<1
PAO13	286	429	1.4555	<0.01
PAO14	328	529	1.4447	<0.01
PAO15	389	535	1.4551	<1
EST16	224	447	1.4421	<1
EST17	196	497	1.4498	<1
EST18*				
PPD19*				<1
BL20	201	455	1.4700	
BL21	257	444	1.4702	
BL22	250	455	1.4678	
BL23	289	519	1.4667	

Table 6. Indicators for Production of Smoke

* Data for MIN7 and EST18 is incomplete due to the late arrival of the samples for testing. PPD19 did not undergo these tests because it is intended for use only as an additive.

Vapor pressure is not a very good indicator of the relative performance of the products in Table 6 since all of them feature very low pressures. There is slightly more variation in refractive index, with most of the mineral oil products (MIN1, MIN2, MIN4, MIN5, and MIN6) exhibiting higher values than the other types of products. Several of the blends also had high refractive indices. Considerable variation was found in the boiling range of the products. It has been determined through experience that the current fog oil, MIN1, has a boiling range well-suited to the production of smoke. The majority of the products exhibited final boiling points similar to, or even higher than, MIN1, which indicates good obscurant performance. Two of the solvents, SOL8 and SOL9, which had much lower boiling ranges, were the major exceptions. However, the blend BL20 is a mixture of MIN1 and SOL8, and the addition of SOL8 did not significantly decrease the boiling range of the mineral oil MIN1. The other two flow enhancer/mineral oil blends, BL21 and BL22, also exhibited boiling ranges similar to, or slightly lower than, the base mineral oil alone. BL23, which is a combination of MIN1 and the pour point depressant PPD19, actually shows an almost 50-degree increase in boiling range.

In conclusion, the blending of the flow enhancement products or the pour point depressant does not appear to significantly reduce the refractive index or the boiling range of the mineral oil into which it is blended.

3.3 Ease of Use

A product that requires no extra treatment at low temperatures would be the easiest to use. The products from Table 1 that require no flow enhancement at low temperatures would be simplest to use, because usage would not change regardless of climate. This includes MIN4, PAO12, and PAO15.

It would require extra effort to use a product that needed to be blended with a flow enhancer at low temperatures. PPD19 would be difficult to blend in the field because of the small and precise quantity required; in addition, the product itself is nearly a solid at low temperatures. The other flow enhancement products would be considerably easier to blend as needed in cold weather. These products include PAO13, EST17, PAO11, PAO14, EST16, EST18, SOL8, SOL9, and SOL10.

The use of product PPD19 would be greatly facilitated if this pour point depressant were blended into the mineral oil before delivery.

4.0 SAFETY ASSESSMENT OF PRODUCTS

The draft revision known as MIL-PRF-12070E contains a specific set of handling safety and toxicological criterion that must be satisfied by any material to be used as fog oil. The two metrics related to the safety of handling the products can also be found in previous versions of the military specification governing fog oil: the flash point of the material must be above 160°C by ASTM 92; and the product must not require labeling under the OSHA Hazard

Communication Standard (HCS) 29 CFR 1920.1200. The metrics introduced by MIL-PRF-12070E (which has not been officially approved) all relate to toxicology, and have not been previously applied to fog oils. These proposed metrics state that each batch of fog oil must pass a mouse skin painting study with no excess of malignant tumors, which would mean that the product would not be a carcinogen. Specifications for the conduct of this test are available from the National Toxicology Program (NTP) (8). If results of the mouse skin paint study are not available, the proposed specification states that a product must pass two other tests instead. The first is a modified Ames test, ASTM 1687. This is a test for mutinagenicity, and the result must be a mutinagenicity index of less than 1.0. The second test is an ultraviolet absorbance test, which is used to determine the content of polynuclear aromatics (PNA); PNAs are thought to be the carcinogenic component of mineral oil. The procedure for this test is described in FDA 21 CFR 178.3620b. The product must have an absorbance of less than 200 units between 280 and 289 nanometers wavelength.

Flash point and OSHA labeling requirements are listed on the Material Safety Data Sheet (MSDS) of every product, making that information simple to gather. Information related to the three toxicology tests was not as readily available. Since they are not routinely performed, little existing information was gathered from manufacturers regarding results of these tests. The information that was available is presented in Table 7.

Table 7. Safety of Handling and Toxicological Test Data According to MIL-PRF-12070E

Product	Flash Point (°C)	HCS Label	Mouse Skin Study	Modified Ames Test	UV Absorbance
MIN1	168	No			
MIN2	182			0.4	6.7
MIN3	175				
MIN4	154	No			
MIN5	>177	No			<4.0
MIN6	174	No			
MIN7	182	No		0	0.269
SOL8	91	Combustible	Promote but not initiate tumors	inactive	<1.5
SOL9	77	Combustible	Promote but not initiate tumors	inactive	<4.0
SOL10	99	No			
PAO11	160	No			<4.0
PAO12	224	No			<4.0
PAO13	222	No			
PAO14	160	No			

Table 7. Safety of Handling and Toxicological Test Data According to MIL-PRF-12070E					
Product	**Flash Point (°C)**	**HCS Label**	**Mouse Skin Study**	**Modified Ames Test**	**UV Absorbance**
EST16	172	No			
EST17	220	No			
EST18	157				
PPD19	190	No			<0.15
BL20	120				
BL21	166				
BL22	166				
BL23	178				

As shown in the above table, MIN4, SOL8, SOL9, SOL10 and EST18 do not meet the minimum flash point limit. SOL8 and SOL9 also require labeling under the OSHA Hazard Communication Standard; both must be labeled "Danger! Combustible." However, these products would not be used alone as a fog oil because they are of such low viscosities at low temperatures that they would be blended with mineral oil for use in cold weather operations. A blend of SOL8 and the mineral oil currently used as fog oil, MIN1, was formulated and labeled BL20. It was found that the flash point of this blend was 120°C, which is still lower than the 160°C minimum. The other blends, BL21 through BL23, meet the flash point requirement. The blend must ultimately meet the requirements of the specification.

Manufacturers conducted mouse skin paint tests on products similar to SOL8 and SOL9. It was found that while these products would not initiate tumors, they would promote tumors once initiated. These tumors might be the result of the irritation caused by the repeated application of this or any other light mineral oil distillate to shaved skin. Since the products are not mutagenic and have minimal specific organ toxicity, it is considered unlikely that they would be complete carcinogens (6), (7).

Little data is available for the three tests required by MIL-PRF-12070E, which are the most critical in determining if a product may be toxicologically hazardous. Therefore, supplemental toxicology and related information was gathered. This information includes data that was readily available from manufacturers but is not specifically required by MIL-PRF-12070E. Details are presented in Table 8. Again, it should be noted that information on each of the products is incomplete. Additionally, this toxicological information is based on the pure product as an oil; the toxicology of the products in a blend or as a fog oil could be very different.

Table 8. Supplemental Toxicology Information

Product	Description	FDA/USDA Food Additive	Biodegradability	Decomposition Products	DOT Restrictions
MIN1	Napthenic petroleum hydrocarbon	No		CO	None
MIN2	Highly refined hydrotreated distillate	No		CO, CO_2	None
MIN3	Highly refined paraffin	No			
MIN4	Hydrotreated light naphthenic distillate with additives	No		CO, others	None
MIN5	Fully refined hydrogenated hydrocarbon	Direct		CO, CO_2	None
MIN6	Severely refined hydrotreated hydrocarbon	Indirect	Low	CO, CO_2	None
MIN7	Highly refined hydrocracked hydrocarbon	No		CO2, CO	None
SOL8	Synthetic saturated isoparaffin	Direct	Low	CO, Sulfur Oxides, aldehydes	Combustible Liquid
SOL9	Severely refined hydrotreated hydrocarbon	Indirect	Low	CO, Sulfur Oxides, aldehydes	Combustible Liquid
SOL10	Highly refined mineral oil with petroleum distillate	Indirect	Low	SO_2, CO	
PAO11	Synthetic polyalphaolefin (PAO)	Indirect	80%	CO, CO_2	None
PAO12	PAO	Indirect	60%	CO, CO_2	None
PAO13	PAO	Indirect	Low	CO, CO_2	
PAO14	PAO	Indirect	Low	CO, CO_2	
PAO15	PAO	No		CO, CO_2	None
EST16	Synthetic diester, isodecyl pelargonate	No	98%	CO, CO_2	None
EST17	Mixture of synthetic diesters	No	100%	CO, CO_2	None
EST18	Single synthetic ester	No			
PPD19	Acrylic copolymer/ neutral oils	Indirect		Methacrylate Monomers	None

The information in the "Description" column is presented to give a general idea of the manufacturing background of the product. Mineral oils that have been lightly refined are classified as carcinogenic by the International Agency for Research on Cancer (IARC), while highly refined mineral oils have not been proven to be carcinogenic (4). Although in-depth carcinogenicity tests have not been performed on most types of polyalphaolefins (PAO), they are a synthetic product produced under controlled conditions and should not contain any PNAs or other components that would pose a toxicological risk to humans. Synthetic esters are believed to pose even less toxicological risk for humans than PAOs.

The third column indicates whether a product is certified by the FDA or the USDA for use as a lubricant in food processing applications. A product permitted for use in indirect contact with food will be present in the food in quantities on the order of a few parts per million. A product permitted for use in direct food contact will be present in slightly larger quantities and must meet stricter requirements (5).

Biodegradability is one measure of the duration of a product's effect on the environment as a fog oil. However, there is no universally accepted test used to measure biodegradability, and the data presented in Table 9 must be used only to form a preliminary idea of the biodegradability of the products. It is known that, in general, mineral oils have a very low degree of biodegradability (less than 40%), PAO typically has a somewhat greater degree of biodegradability, and synthetic esters can be completely biodegradable.

Based on the information presented in Tables 7 and 8, the products were divided into three groups according to predicted overall "safety", which is a combination of shipping and handling factors, human toxicology, and environmental impact. The divisions are based on the characteristics of the products as oils, since it is beyond the scope of this work to investigate their toxicology as a fog. The groups are presented in Table 9.

Table 9. Safety Ranking of Products		
Rank	Product	Description
1	EST16	Single synthetic ester
	EST17	Mixture of synthetic esters
	PAO11	Synthetic polyalphaolefin
	PAO12	Synthetic polyalphaolefin
	PAO15	Synthetic polyalphaolefin
	PAO13	Synthetic polyalphaolefin
	PAO14	Synthetic polyalphaolefin
2	EST18	Newly developed synthetic ester
	MIN7	Pure, highly refined mineral oil
	MIN2	Pure, highly refined mineral oil
	MIN5	Pure, highly refined mineral oil
	MIN3	Pure, highly refined mineral oil
	MIN6	Pure, highly refined mineral oil
	SOL8	Synthetic, saturated isoparrafin
	SOL9	Pure, highly refined mineral oil solvent
3	PPD19	Pour point depressant
	MIN4	Mineral oil containing pour point depressant, other additives
	MIN1	Current napthenic fog oil
	SOL10	Solvent mixture: highly refined min. oil/petroleum distillate

Group One is comprised of products that are expected to pose a low level of risk for several reasons. First, each of them is safe to handle, none has a flash point that falls below the minimum 160°C requirement, and none requires special HCS labeling. Second, each is either highly biodegradable or from a class of products typically more biodegradable than mineral oil. Finally, no negative toxicological data was found for any of the products. All of the products are synthetic and produced under controlled conditions that do not allow the introduction of harmful PNA. The esters received higher ranks than the PAO products due to their higher degree of biodegradability and the general acceptance of the fact that esters are more benign than PAO.

Group Two products may provide slightly more risk than the Group One products. EST18 would be expected to be very safe for the reasons presented for the other esters above. However, it is in Group Two because it is a newer product, and relatively little characterization has been made of its properties.

The mineral oil products that are in Group Two are safe to handle (flash point is above minimum, no HCS label required). Since they are mineral oils, they would be expected to exhibit limited biodegradability. However, they are highly refined mineral oils and should not pose toxicological hazards. MIN7 has been tested for mutagenicity and UV absorbance, and performed very well in both tests (Table 7). MIN2 has undergone similar testing; test results were not as good as those for MIN7 but were still very good. MIN5 has been approved by the FDA as a direct food additive, and test results show it to have a very low level of UV absorbance. MIN3 and MIN6 are probably just as toxicologically benign but have not been similarly tested.

SOL8 and SOL9 both have low flash points. SOL8 has a higher flash point than SOL9, but BL20 (consisting of MIN1 and SOL8) did not even meet the 160°C minimum requirement. Both products also require labeling under HCS; however, that requirement might not apply to a blend. Neither of the products could be expected to be biodegradable. However, SOL8 is a synthetic product that has been shown to have a very low UV absorbance, and SOL9 is a highly refined mineral oil product. As a component of a blend, neither product would be expected to exhibit adverse toxicological effects.

Group Three includes products whose effects are more uncertain than the Group One and Two products. For example, PPD19 by itself should be safe to handle and in a blend would be used in such low quantities that its environmental impact would be negligible. Based on the FDA's approval of the product for use as an indirect food additive, PPD19 should be toxicologically safe. However, to gain complete confidence in its toxicological safety, the exact effect of the pour point depressant on the product to which it is added would require testing. Similar comments apply to MIN4. This product contains a pour point depressant similar to PPD19. This product also has a flash point slightly below 160°C.

MIN1 is safe for handling. However, data provided by the supplier of this product indicates that it is not as highly refined as the other products identified by this study. The product's MSDS lists aromatic hydrocarbons as one component of the mixture of hydrocarbons present, but the quantity of aromatics is not given, nor is there an indication of whether those aromatics include polynuclear aromatics (PNA).

SOL10 has a low flashpoint and almost no information was available about the exact components of the mixture of hydrocarbons present in the product.

5.0 COST ASSESSMENT OF PRODUCTS

An acceptable fog oil product must not be prohibitively expensive. A ranking of the products according to their cost is presented in Table 10. This ranking is not based on the cost per drum of the products. Many of these products would be used only as a small component of a blend with mineral oil. Therefore, these products are ranked based on the per drum cost of a blend with mineral oil at -32°C (-25°F). The appropriate blend ratio for several of the products was determined through analytical testing at TFLRF (SwRI). Due to the large number of products, the rest of the blend ratios were approximated based on low-temperature viscosity and blend ratios of similar products. A change in the blend ratio could significantly change the total cost of the blend. The cost per drum of a blend at -18°C (0°F) is also given. The cost of each of the different products was given by either the manufacturer or a distributor, and was based on a yearly order of 1000 55-gallon drums.

To use Table 10 to determine the cost of a given product, SOL9 for example, find the row with that product in the first column. The second column gives the price of a 55-gallon drum of the product; in the case of SOL9, this is $137. The third and fourth columns give information on the cost of that product blended with MIN1 in a ratio suitable for use at -32°C (-25°F). From column three it can be seen that SOL9 would comprise 20% of such a blend; thus MIN1 would be present at 80%. Column four shows that, based on the prices of drums of MIN1 and SOL9, a cost for a blended drum would be $113. Columns five and six contain similar information for blends that would be suitable for use at -18°C (0°F).

Table 10. Cost Ranking of Products					
Product	Cost Per Drum ($)	Component of Blend at -32°C (%)	Cost of Drum Blended for -32°C ($)	Component of Blend at -18°C (%)	Cost of Drum Blended for -18°C ($)
MIN1	107	100	107	100	107
PPD19	696	0.25	108	0.25	108
SOL9	137	20	113	5	108
SOL8	175	30	127	10	114
MIN7	193	100	193	100	193
PAO11	329	40	196	10	129
MIN5	202	100	202	100	202
MIN4	275	100	275	60	208
EST16	770	30	306	10	173
EST18	825	30	322	10	179
PAO12	342	100	342	60	248
MIN6	399	100	399	100	399
PAO15	408	100	408	60	288
SOL10	562	90	517	50	335
PAO14	1304	40	586	10	227
EST17	758	90	693	50	433
PAO13	987	90	899	50	547
MIN2	N/A	100		100	
MIN3	N/A	100		100	

6.0 CONCLUSIONS AND RECOMMENDATIONS

- Several products are available that are capable of reducing the viscosity of mineral oil as well as diesel fuel.
- Products are also available that could replace mineral oil and would require no extra additives during cold weather.
- Tradeoffs between cost, safety, and performance will have to be made during the product selection process.
- More testing is needed to determine the performance of each product as a smoke screen.
- Testing is needed to determine the effects of the vaporization/condensation process on product safety.

7.0 REFERENCES

1. U.S. Military Specification MIL-F-12070D, "Fog Oil", October 14 1992.

2. U.S. Military Performance Specification MIL-PRF-12070E, "Fog Oil", Draft, 1997.

3. National Academy Press, "Toxicity of Military Smokes and Obscurants", Volume 1, 1997.

4. International Agency for Research on Cancer (IARC), "Overall Evaluations of Carcinogenicity: An Updating of IARC Monographs Volumes 1 to 42", Supplement No. 7, 1987.

5. U.S. Food and Drug Administration, Bureau of Foods, "Toxicological Principles for the Safety Assessment of Direct Food Additives and Color Additives Used in Food (also known as "Redbook"), 1982.

6. Exxon Chemical, "Toxicological Assessment for Exxsol©D Fluids," Revision 1, January 1997.

7. Exxon Chemical, "Toxicological Assessment for Isopar© Fluids," Revision 1.

8. National Toxicological Program, "Specifications for the Conduct of Studies to Evaluate the Toxic and Carcinogenic Potential of Chemical, Biological and Physical Agents in Laboratory Animals for the National Toxicology Program (NTP)."

APPENDIX A
MANUFACTURERS OF PRODUCTS

MANUFACTURERS OF PRODUCTS

MIN1 (Current Fog Oil)
American Lubricating Company
500 S. Front St./P.O. Box 258
Memphis, Tennessee 38101
Phone: (901) 527-4707
FAX: (901) 525-7670
Contact: Chip Armstrong

MIN7 (Hydroclear Industrial Oil 70)
Conoco Inc.
P.O. Box 4784
Houston, TX 77210
Phone: 1-800-643-9195/(281)293-2105
Contact: Diane Trepagnier

PAO15 (Emery 3004)
EST16 (Emery 2911)
EST17 (Emery 2958)
Henkle Corporation/Chemicals Group
4900 Este Avenue
Cincinnati, OH 45232
Phone: 1-800-254-1029
FAX: (513) 482-2173
Contact: Carol Jones

SOL10 (Pure Flush)
Lubriplate Lubricants/ Division of Fiske Brothers Refining Company
129 Lockwood Street
Newark, NJ 07105
Phone: (973) 589-9150
FAX: (973) 589-4432
Contact: Dan Moroses

PPD19 (Acryloid 150)
RohMax USA
P.O. Box 972
Delran, NJ 08075
Phone: (609) 461-4517
FAX: (609) 461-4351
Contact: Armand Bianchini

MIN5 (LP 100)
Witco Corporation/Petroleum Specialties Group
One American Lane
Greenwich, CT 06831-2559
Phone: 1-800-494-8673
FAX: (203) 552-2724
Contact: Lenny Jacobs

PAO11 (Durasyn 162)
PAO12 (Durasyn 164)
Amoco Chemicals
801 Warrenville Road/Mail Code 6018
Lisle, IL 60532
Phone: 1-800-621-4567
FAX: (630) 434-6112
Contact: Shari Elfilne

PAO13 (CP-4614 5-F)
PAO14 (CP-4614 15-F)
CPI Engineering Services, Inc.
2300 James Savage Rd.
Midland, MI 48642
Phone: (517) 496-3780
FAX: (517) 496-2313
Contact: Jason Foken

SOL8 (Isopar M)
SOL9 (Exxsol D-80)
Exxon Company USA
P.O. Box 2180
Houston, TX 77252-2180
Phone: 1-800-443-9966
FAX: (713) 656-6922
Contact: Debra Teagle

MIN6 (NF)
EST18 (NF/LV)
Paratherm Corporation
1050 Colwell Road
Conshohocken, PA 19428
Phone: 1-800-222-3611 / (610) 941-4900
FAX: (610) 941-9191
Contact: Al Walton

MIN4 (Royco 481)
Royal Lubricants Company, Inc.
Merry Lane/P.O. Box 518
East Hanover, NJ 07936
Phone: (201) 887-7410
FAX: (201) 887-3422
Contact: Lou Fletcher

APPENDIX B

DETAILS FOR TEST OF BOILING RANGE

DETAILS FOR TEST OF BOILING RANGE

The boiling range of the potential fog oil products was tested according to ASTM D 2887, "Standard Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography." In this method, a gas chromatograph is used to simulate distillation of the petroleum product. As the temperature of the column is raised over a given time period and the sample gradually boils off, a chromatogram is developed. This chromatogram is a record of the quantity of hydrocarbons that boil off over time as the temperature increases. A calibration curve is plotted on the same scale and used to correlate the chromatogram to boiling points. The test operator uses the slope of the chromatogram to determine the time at which boiling began and ended. These two times are given as input to a computer software package which then calculates the area under the chromatogram. The reported Initial Boiling Point (IBP) is defined to occur when 0.5% of the sample has boiled off; this is calculated by the software based on the total area under the chromatogram curve. The calibration curve is then used to determine the temperature at the time of IBP. The Final Boiling Point (FBP) is defined to occur after 99.5% of the sample has boiled off, and is determined in a manner similar to that used to find the IBP.

According to ASTM D 2887, the repeatability of test results by the same operator using the same apparatus is between 2.5 and 6.0°C (5 and 11°F). The reproducibility of test results by different operators in different laboratories ranges from 6.5 to 23.0°C (12 to 42°F).

BL20 is a blend of MIN1 and SOL8. If the chromatograms for MIN1 and SOL8 are compared to that of BL20, the two separate components can both be seen clearly in BL20. The IBP for BL20 is not as low as that of SOL8; nor is the final boiling point as high as MIN1. This could be attributed to two possible factors: 1) The test operator's choice of beginning and ending boiling times, or 2) The reduced significance of the highest and lowest ends of the products when blended together.

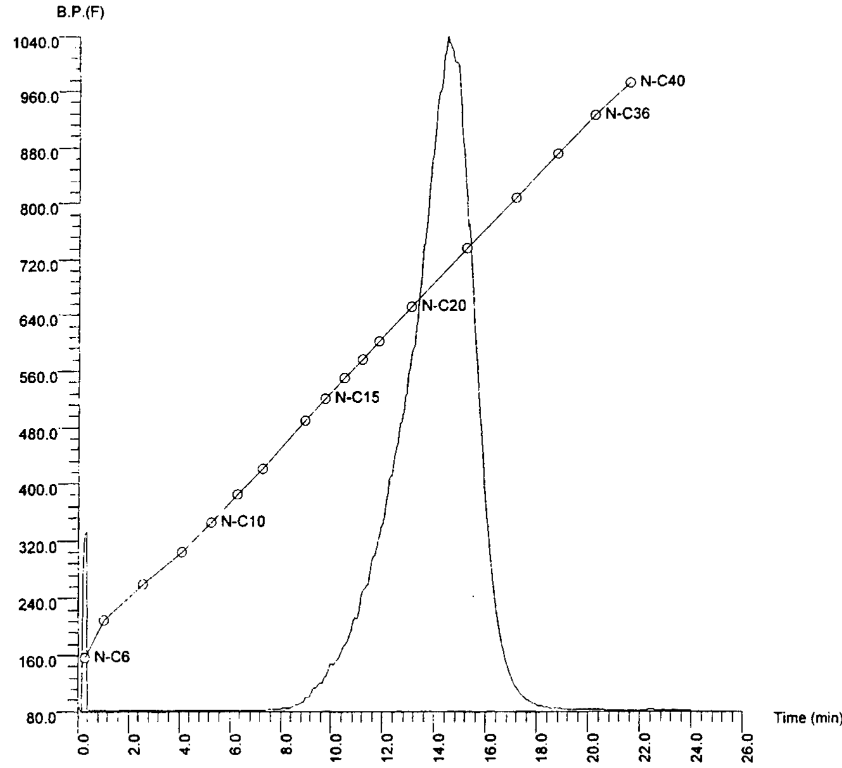

Figure B-1. Chromatogram of MIN1

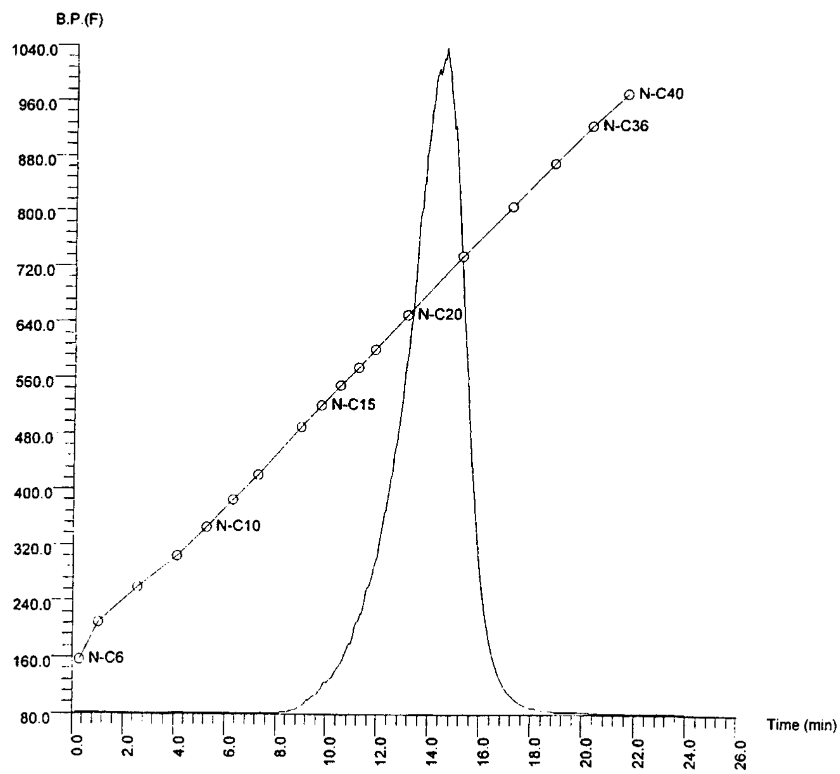

Figure B-2. Chromatogram of MIN2

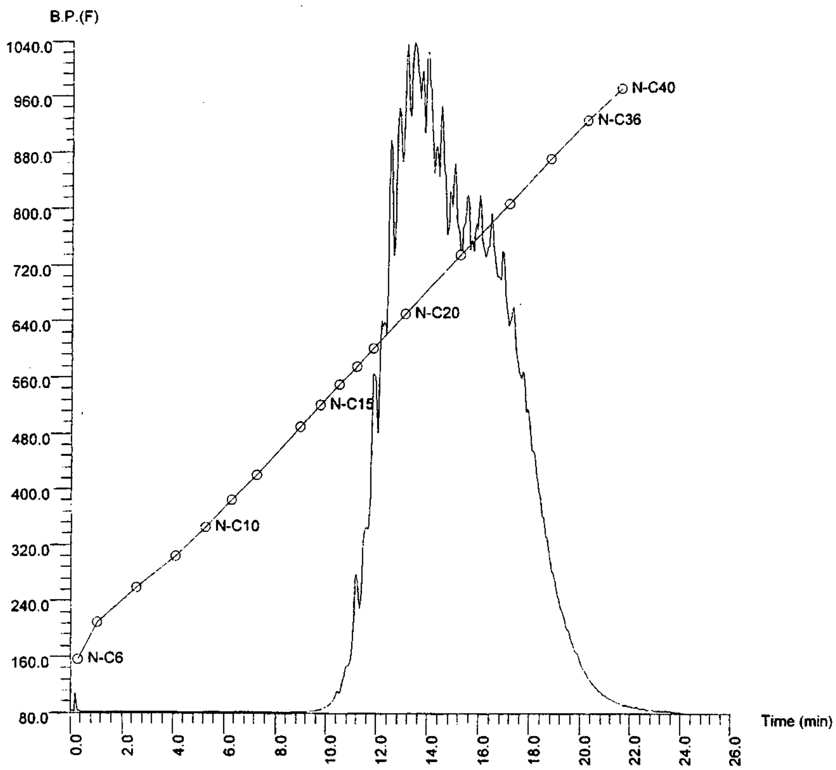

Figure B-3. <u>Chromatogram of MIN3</u>

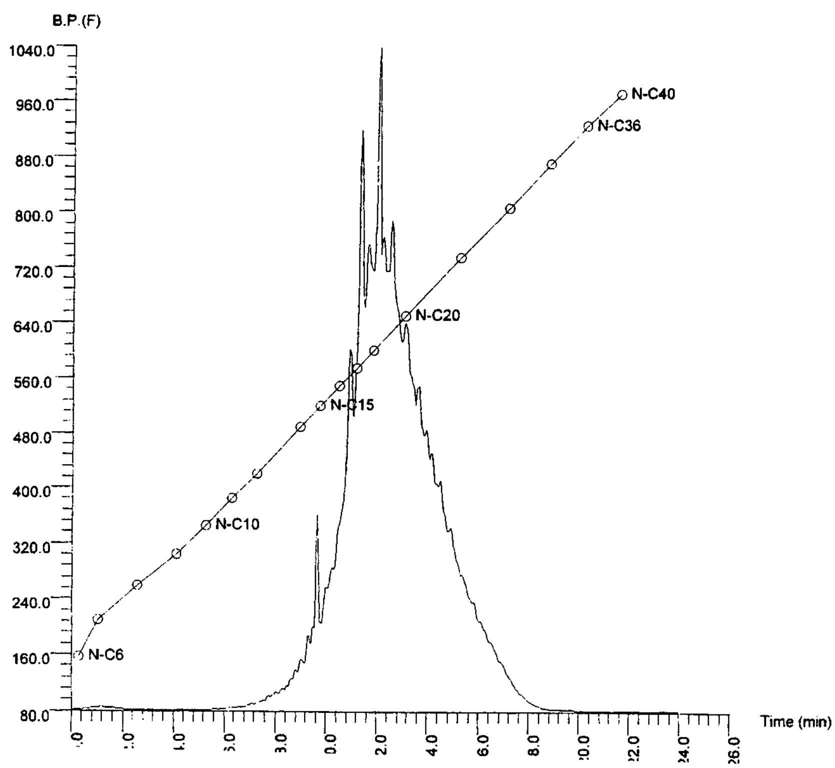

Figure B-4. <u>Chromatogram of MIN4</u>

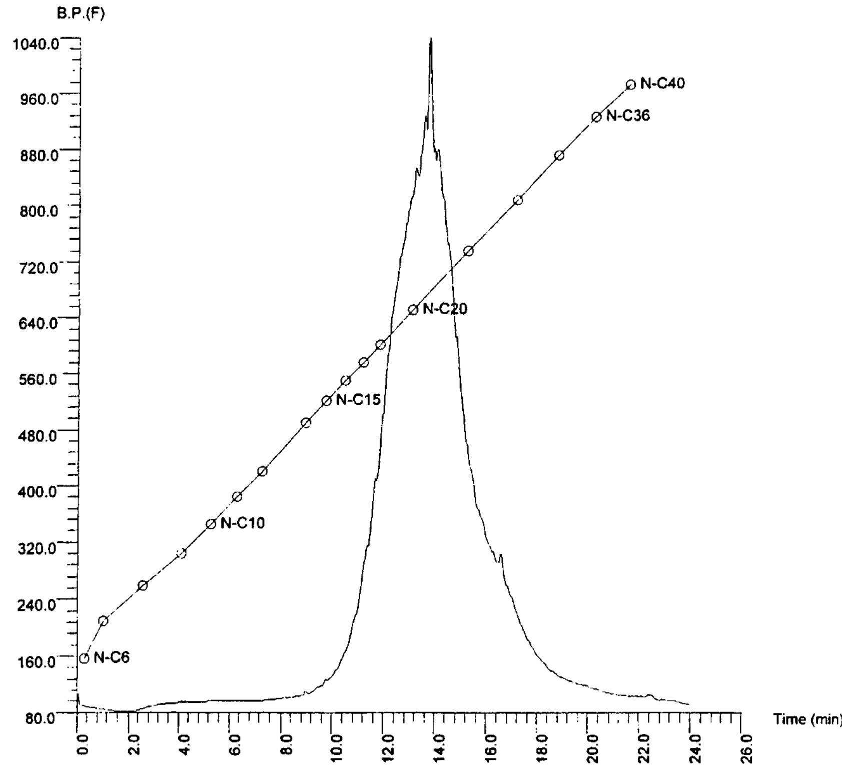

Figure B-5. Chromatogram of MIN5

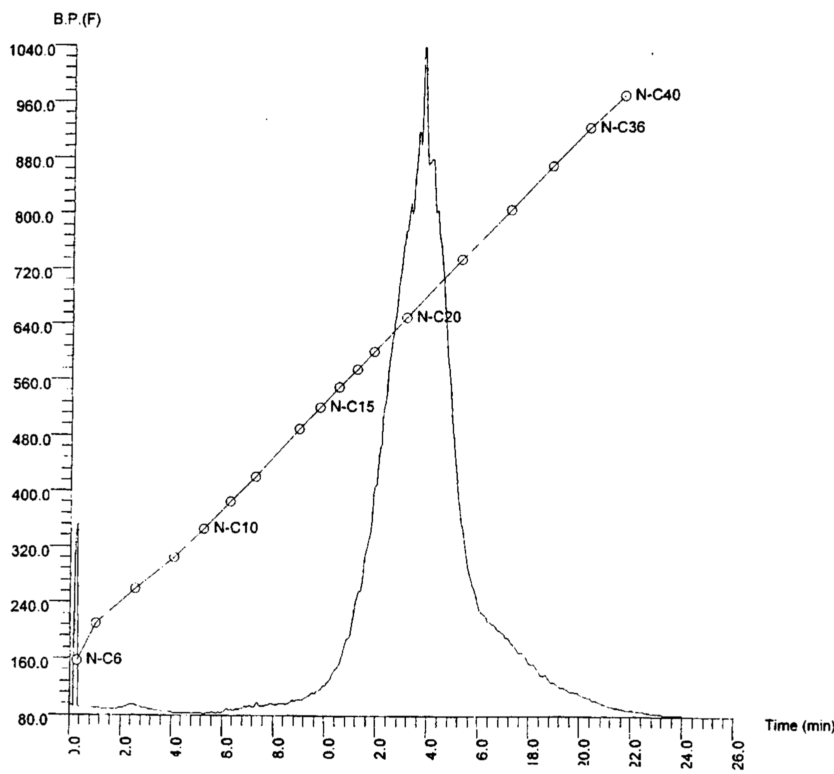

Figure B-6. Chromatogram of MIN6

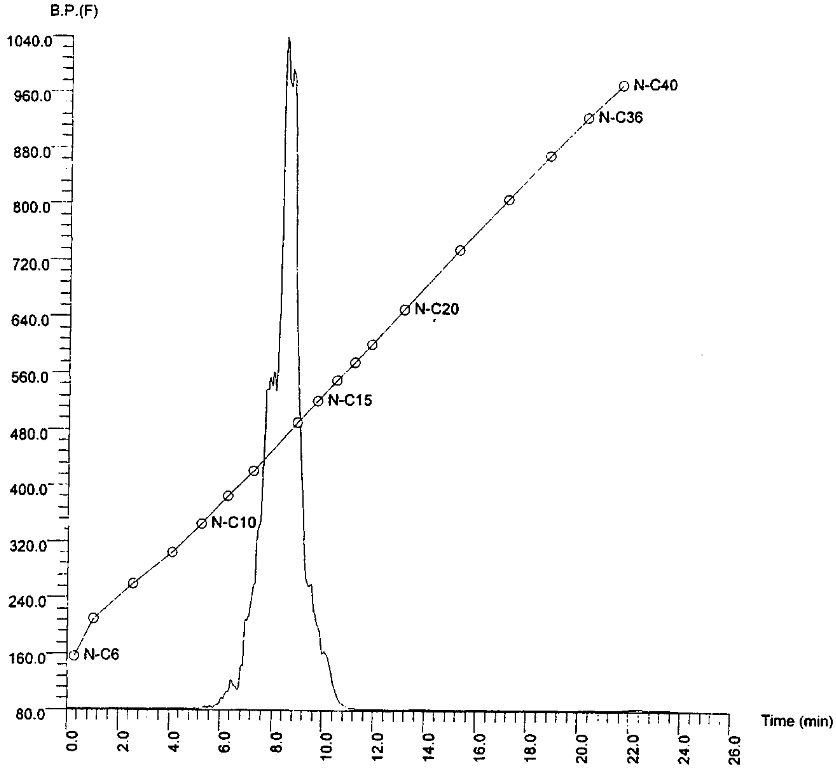

Figure B-7. Chromatogram of SOL8

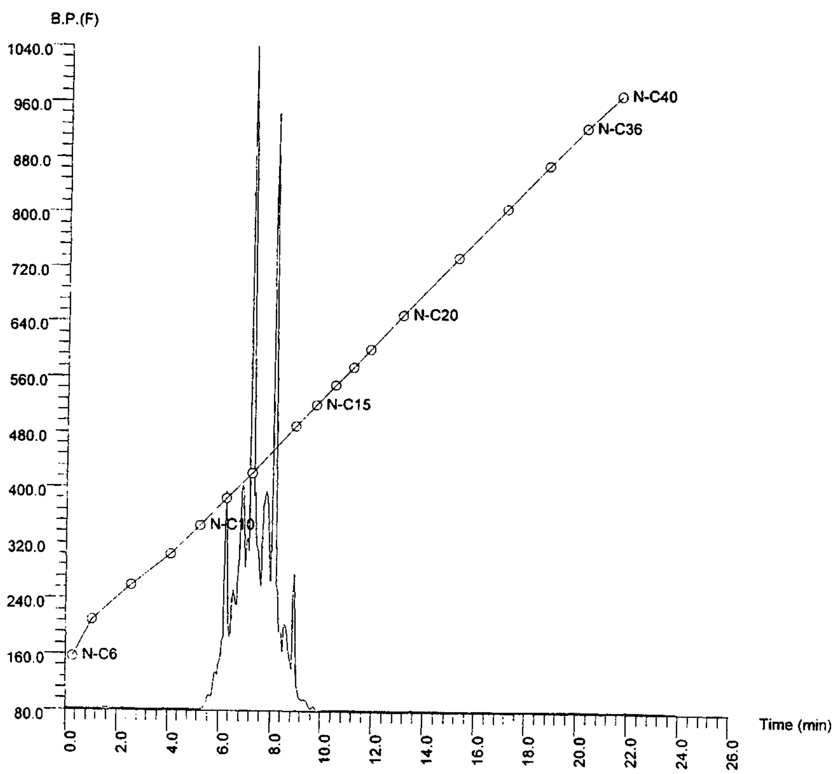

Figure B-8. Chromatogram of SOL9

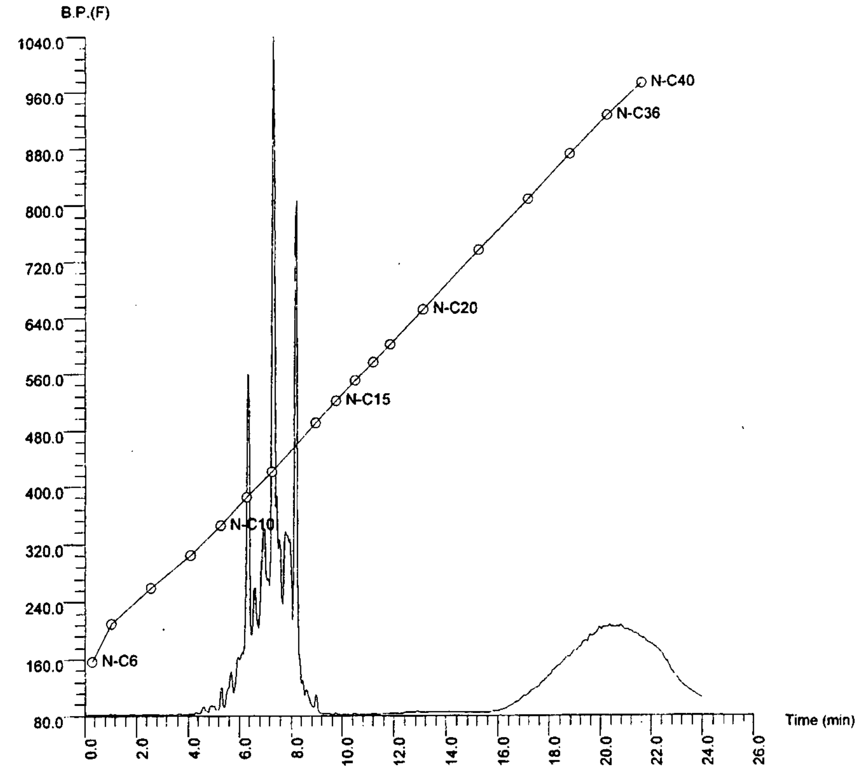

Figure B-9. Chromatogram of SOL10

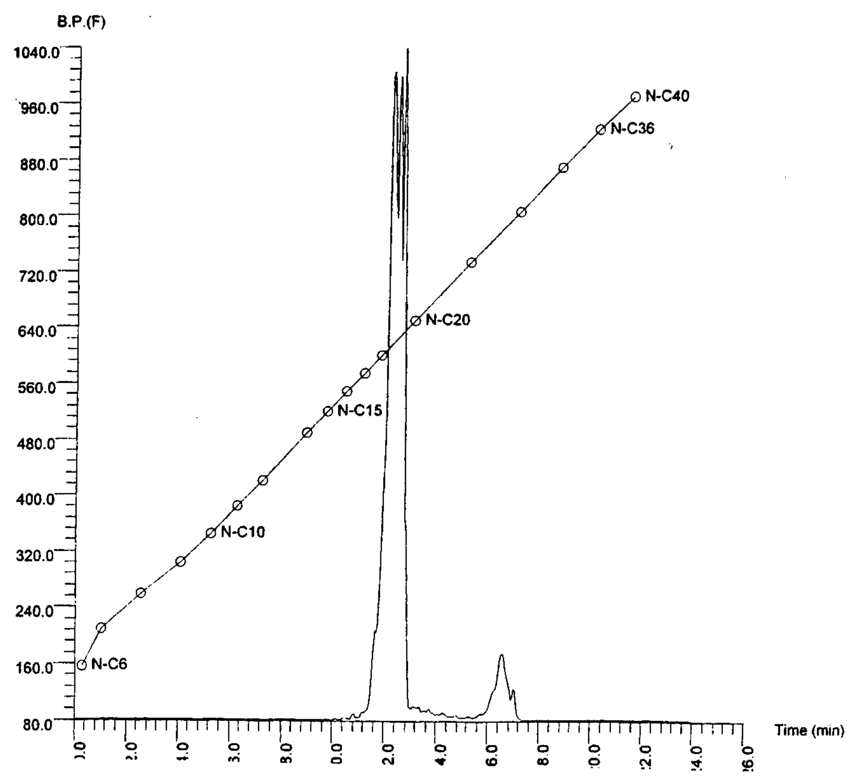

Figure B-10. Chromatogram of PAO11

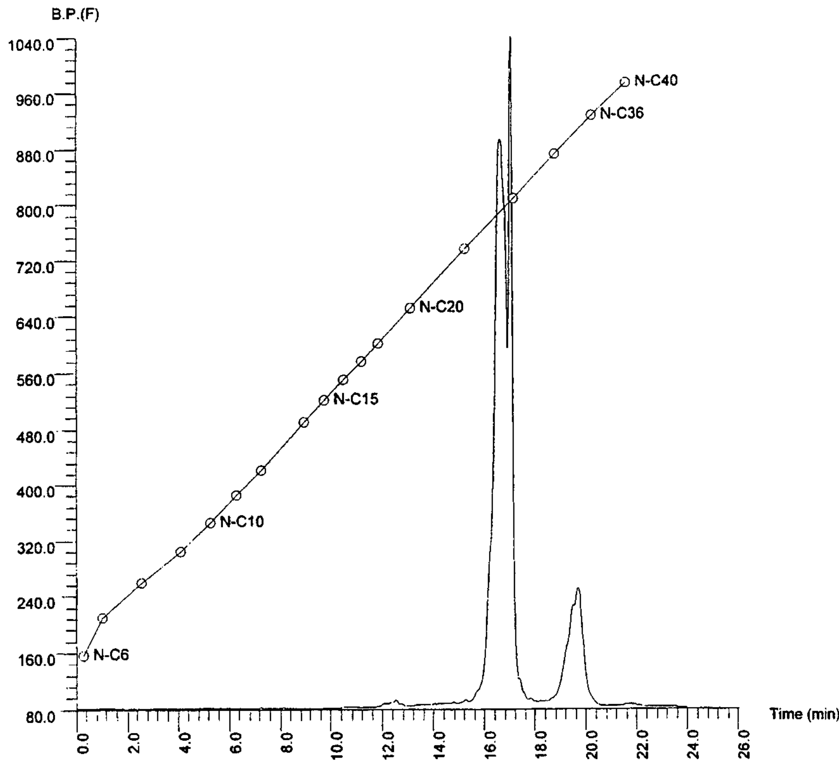

Figure B-11. Chromatogram of PAO12

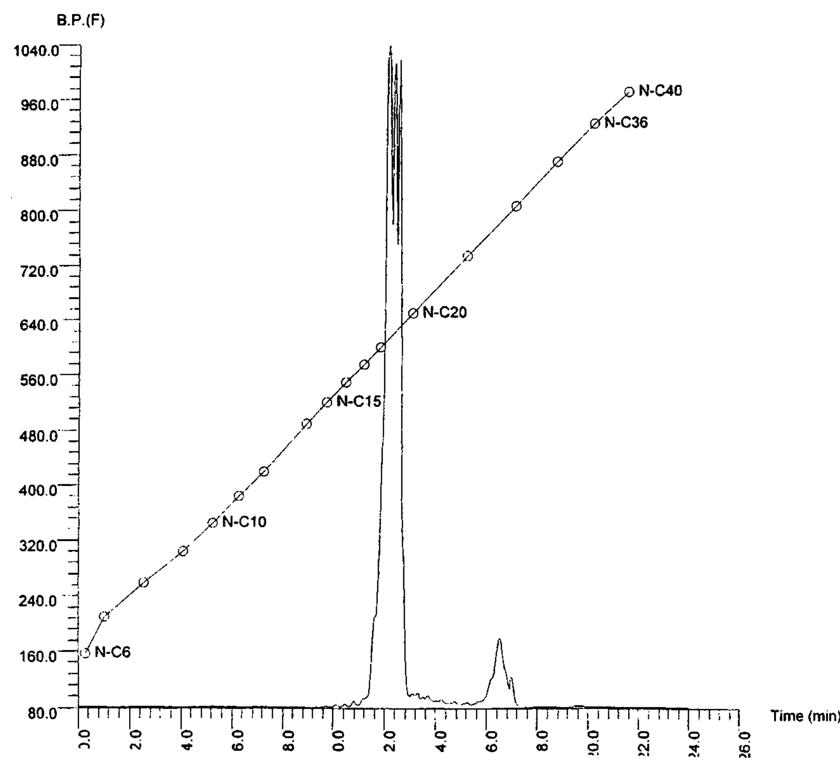

Figure B-12. Chromatogram of PAO13

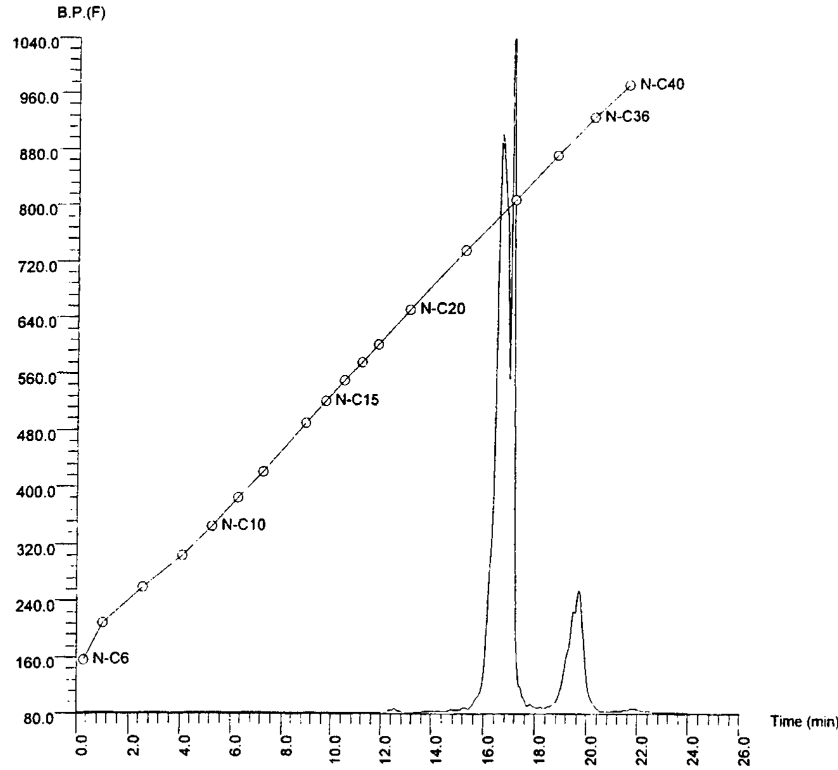

Figure B-13. Chromatogram of PAO14

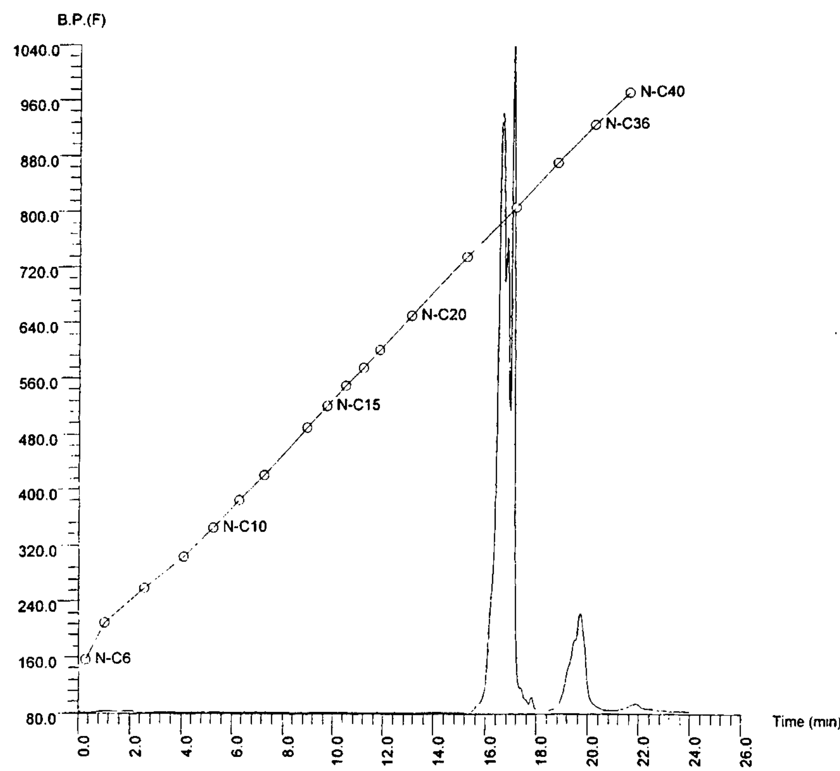

Figure B-14. Chromatogram of PAO15

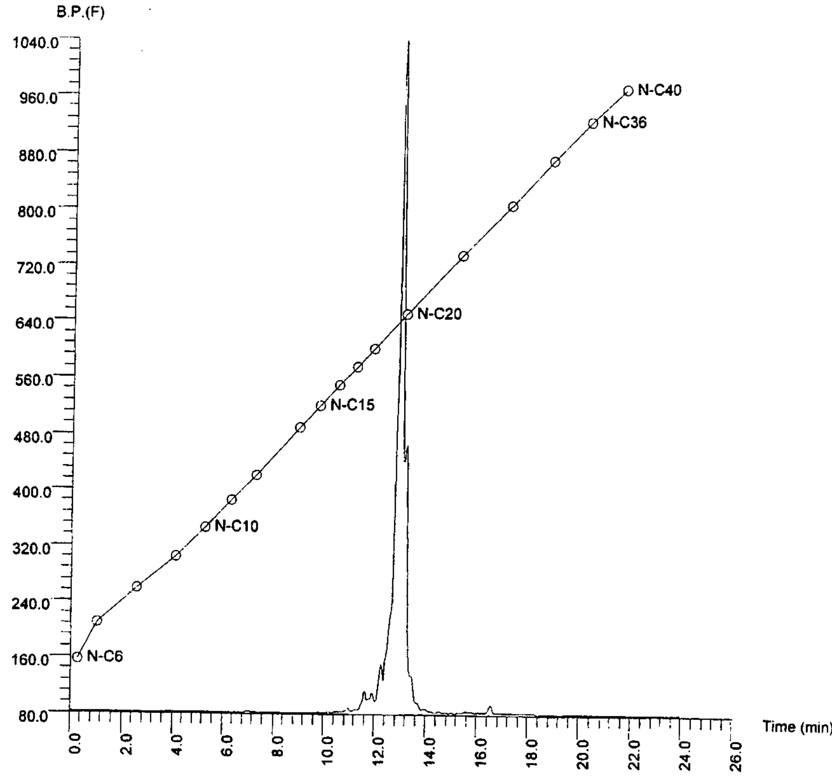

Figure B-15. Chromatogram of EST16

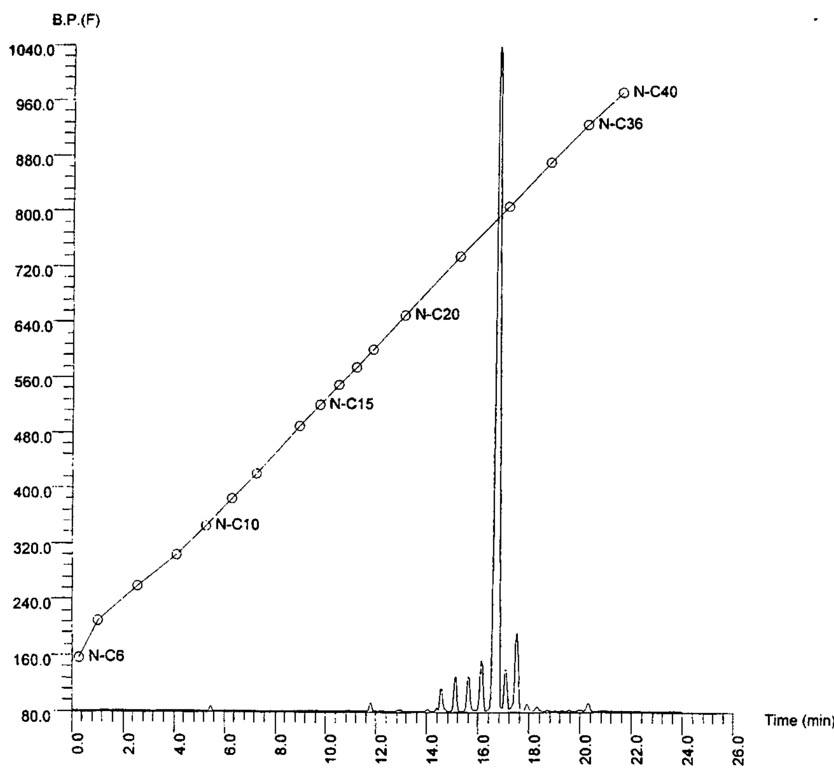

Figure B-16. Chromatogram of EST17

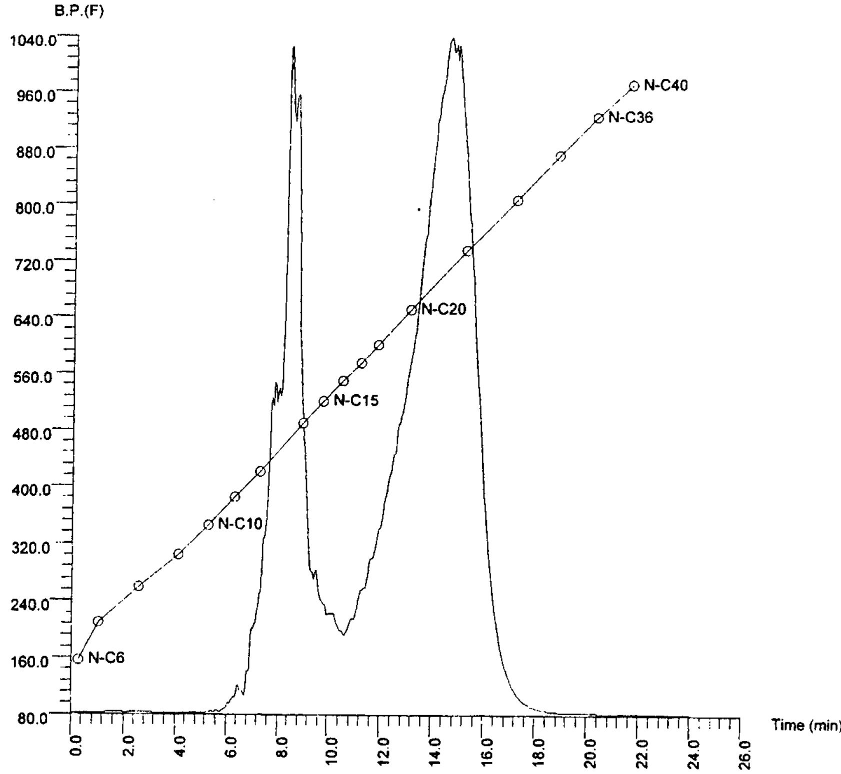

Figure B-17. Chromatogram of BL20

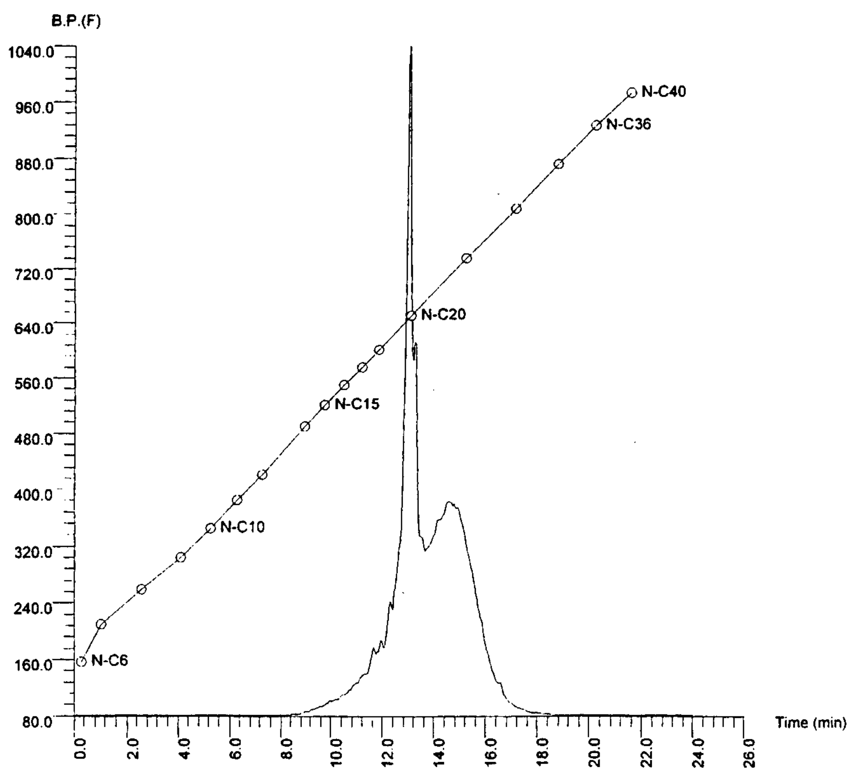

Figure B-18. Chromatogram of BL21

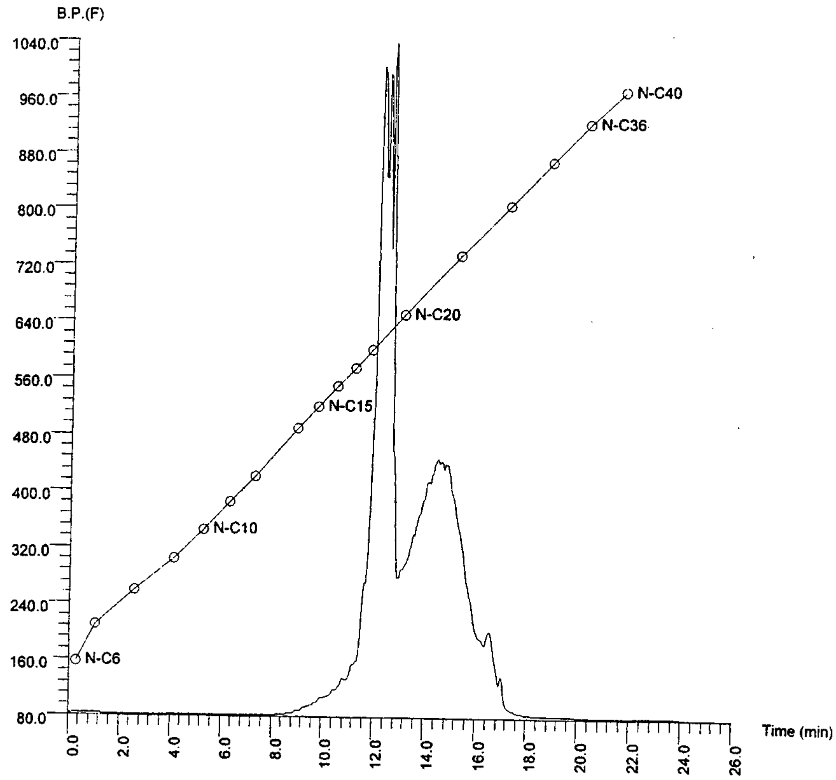

Figure B-19. Chromatogram of BL22

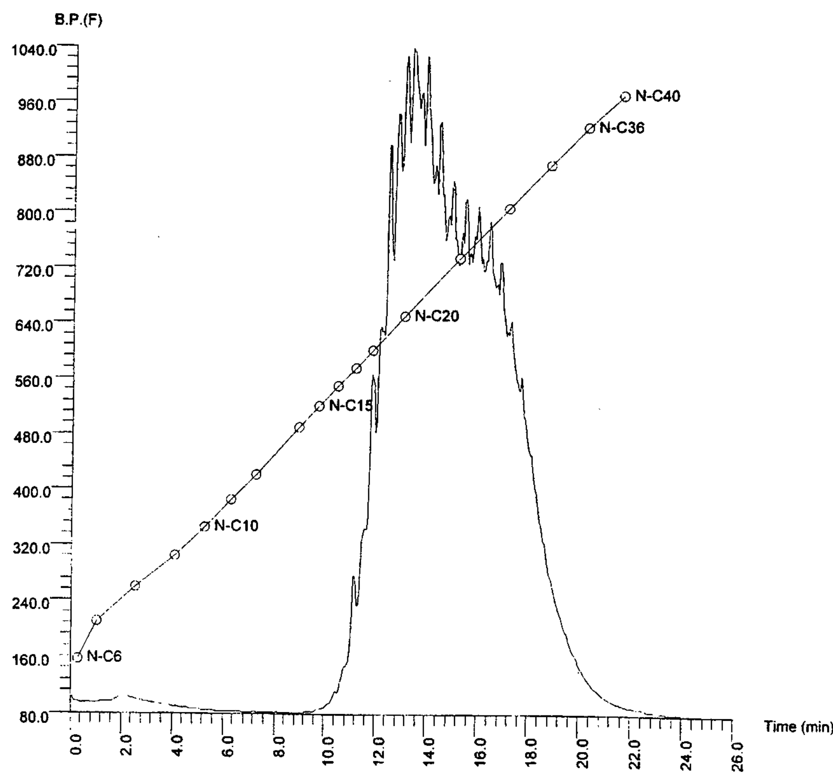

Figure B-20. Chromatogram of BL23

Fuels Distribution List

Department of Defense

DEFENSE TECH INFO CTR ATTN: DTIC OCC 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218	12	JOAP TSC BLDG 780 NAVAL AIR STA PENSACOLA FL 32508-5300	1
ODUSD ATTN: (L) MRM PETROLEUM STAFF ANALYST PENTAGON WASHINGTON DC 20301-8000	1	DIR DLA ATTN: DLA MMSLP 8725 JOHN J KINGMAN RD STE 2533 FT BELVOIR VA 22060-6221	1
ODUSD ATTN: (ES) CI 400 ARMY NAVY DR STE 206 ARLINGTON VA 22202	1	CDR DEFENSE FUEL SUPPLY CTR ATTN: DFSC I (C MARTIN) DFSC IT (R GRAY) DFSC IQ (L OPPENHEIM) 8725 JOHN J KINGMAN RD STE 2941 FT BELVOIR VA 22060-6222	1 1 1
HQ USEUCOM ATTN: ECJU L1J UNIT 30400 BOX 1000 APO AE 09128-4209	1	DIR DEFENSE ADV RSCH PROJ AGENCY ATTN: ARPA/ASTO 3701 N FAIRFAX DR ARLINGTON VA 22203-1714	1
US CINCPAC ATTN: J422 BOX 64020 CAMP H M SMITH HI 96861-4020	1		

Department of the Army

HQDA ATTN: DALO TSE DALO SM 500 PENTAGON WASHINGTON DC 20310-0500	1 1	CDR ARMY TACOM ATTN: AMSTA IM LMM AMSTA IM LMB AMSTA IM LMT AMSTA TR NAC MS 002 AMSTA TR R MS 202 AMSTA TR D MS 201A AMSTA TR M AMSTA TR R MS 121 (C RAFFA) AMSTA TR R MS 158 (D HERRERA) AMSTA TR R MS 121 (R MUNT) AMCPM ATP MS 271 AMSTA TR E MS 203 AMSTA TR K AMSTA IM KP AMSTA IM MM AMSTA IM MT AMSTA IM MC AMSTA IM GTL AMSTA CL NG USMC LNO AMCPM LAV AMCPM M113 AMCPM CCE WARREN MI 48397-5000	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
SARDA ATTN: SARD TT PENTAGON WASHINGTON DC 20310-0103	1		
CDR AMC ATTN: AMCRD S AMCRD E AMCRD IT AMCEN A AMCLG M AMXLS H 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001	1 1 1 1 1 1		
U.S. ARMY TACOM TARDEC PETR. & WTR. BUS. AREA ATTN AMSTA TR-D/210 (L. VILLHAHERMOSA) AMSTA TR-D/210 (T. BAGWELL) WARREN, MI 48397-5000	10 1		

Department of the Army

PROG EXEC OFFICER ARMORED SYS MODERNIZATION ATTN: SFAE ASM S SFAE ASM H SFAE ASM AB SFAE ASM BV SFAE ASM CV SFAE ASM AG CDR TACOM WARREN MI 48397-5000	 1 1 1 1 1 1
PROG EXEC OFFICER ARMORED SYS MODERNIZATION ATTN: SFAE FAS AL SFAE FAS PAL PICATINNY ARSENAL NJ 07806-5000	 1 1
PROG EXEC OFFICER TACTICAL WHEELED VEHICLES ATTN: SFAE TWV TVSP SFAE TWV FMTV SFAE TWV PLS CDR TACOM WARREN MI 48397-5000	 1 1 1
PROG EXEC OFFICER ARMAMENTS ATTN: SFAE AR HIP SFAE AR TMA PICATINNY ARSENAL NJ 07806-5000	 1 1
PROG MGR UNMANNED GROUND VEH ATTN: AMCPM UG REDSTONE ARSENAL AL 35898-8060	 1
DIR ARMY RSCH LAB ATTN: AMSRL PB P 2800 POWDER MILL RD ADELPHIA MD 20783-1145	 1
VEHICLE PROPULSION DIR ATTN: AMSRL VP (MS 77 12) NASA LEWIS RSCH CTR 21000 BROOKPARK RD CLEVELAND OH 44135	 1
CDR AMSAA ATTN: AMXSY CM AMXSY L APG MD 21005-5071	 1 1
CDR ARO ATTN: AMXRO EN (D MANN) RSCH TRIANGLE PK NC 27709-2211	 1
CDR AEC ATTN: SFIM AEC ECC (T ECCLES) APG MD 21010-5401	 1
CDR ARMY SOLDIER SPT CMD ATTN: SATNC US (J SIEGEL) SATNC UE NATICK MA 01760-5018	 1 1
CDR ARMY ARDEC ATTN: AMSTA AR EDE S PICATINNY ARSENAL NJ 07808-5000	 1
CDR ARMY WATERVLIET ARSN ATTN: SARWY RDD WATERVLIET NY 12189	 1
CDR APC ATTN: SATPC L SATPC Q NEW CUMBERLAND PA 17070-5005	 1 1
CDR ARMY LEA ATTN: LOEA PL NEW CUMBERLAND PA 17070-5007	 1
CDR ARMY TECOM ATTN: AMSTE TA R AMSTE TC D AMSTE EQ APG MD 21005-5006	 1 1 1
PROJ MGR MOBILE ELEC PWR ATTN: AMCPM MEP T AMCPM MEP L 7798 CISSNA RD STE 200 SPRINGFIELD VA 22150-3199	 1 1
CDR ARMY COLD REGION TEST CTR ATTN: STECR TM STECR LG APO AP 96508-7850	 1 1
CDR ARMY ORDN CTR ATTN: ATSL CD CS APG MD 21005	 1
CDR 49TH QM GROUP ATTN: AFFL GC FT LEE VA 23801-5119	 1
CDR ARMY BIOMED RSCH DEV LAB ATTN: SGRD UBZ A FT DETRICK MD 21702-5010	 1

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CDR FORSCOM ATTN: AFLG TRS FT MCPHERSON GA 30330-6000	 1	CDR ARMY SAFETY CTR ATTN: CSSC PMG CSSC SPS FT RUCKER AL 36362-5363	 1 1
CDR TRADOC ATTN: ATCD SL 5 INGALLS RD BLDG 163 FT MONROE VA 23651-5194	 1	CDR ARMY ABERDEEN TEST CTR ATTN: STEAC EN STEAC LI STEAC AE STEAC AA APG MD 21005-5059	 1 1 1 1
CDR ARMY ARMOR CTR ATTN: ATSB CD ML ATSB TSM T FT KNOX KY 40121-5000	 1 1	CDR ARMY YPG ATTN: STEYP MT TL M YUMA AZ 85365-9130	 1
CDR ARMY QM SCHOOL ATTN: ATSM PWD FT LEE VA 23001-5000	 1	CDR ARMY CERL ATTN: CECER EN P O BOX 9005 CHAMPAIGN IL 61826-9005	 1
CDR ARMY FIELD ARTY SCH ATTN: ATSF CD FT SILL OK 73503	 1	DIR AMC FAST PROGRAM 10101 GRIDLEY RD STE 104 FT BELVOIR VA 22060-5818	1
CDR ARMY TRANS SCHOOL ATTN: ATSP CD MS FT EUSTIS VA 23604-5000	 1	CDR I CORPS AND FT LEWIS ATTN: AFZH CSS FT LEWIS WA 98433-5000	 1
CDR ARMY INF SCHOOL ATTN: ATSH CD ATSH AT FT BENNING GA 31905-5000	 1 1	CDR RED RIVER ARMY DEPOT ATTN: SDSRR M SDSRR Q TEXARKANA TX 75501-5000	 1 1
CDR ARMY AVIA CTR ATTN: ATZQ DOL M FT RUCKER AL 36362-5115	 1	PS MAGAZINE DIV ATTN: AMXLS PS DIR LOGSA REDSTONE ARSENAL AL 35898-7466	 1
CDR ARMY ENGR SCHOOL ATTN: ATSE CD FT LEONARD WOOD MO 65473-5000	 1		
CDR 6TH ID (L) ATTN: APUR LG M 1060 GAFFNEY RD FT WAINWRIGHT AK 99703	 1		

Department of the Navy

OFC CHIEF NAVAL OPER ATTN: DR A ROBERTS (N420) 2000 NAVY PENTAGON WASHINGTON DC 20350-2000	 1	CDR NAVAL AIR WARFARE CTR ATTN: CODE PE33 AJD P O BOX 7176 TRENTON NJ 08628-0176	 1

CDR
NAVAL SEA SYSTEMS CMD
ATTN: SEA 03M3 1
2531 JEFFERSON DAVIS HWY
ARLINGTON VA 22242-5160

CDR
NAVAL SURFACE WARFARE CTR
ATTN: CODE 63 1
CODE 632 1
CODE 859 1
3A LEGGETT CIRCLE
ANNAPOLIS MD 21402-5067

CDR
NAVAL RSCH LABORATORY
ATTN: CODE 6181 1
WASHINGTON DC 20375-5342

CDR 1
NAVAL PETROLEUM OFFICE
8725 JOHN J KINGMAN RD
STE 3719
FT BELVOIR VA 22060-6224

CDR
NAVAL AIR SYSTEMS CMD
ATTN: AIR 4.4.5 (D MEARNS) 1
1421 JEFFERSON DAVIS HWY
ARLINGTON VA 22243-5360

Department of the Navy/U.S. Marine Corps

HQ USMC
ATTN: LPP 1
WASHINGTON DC 20380-0001

PROG MGR COMBAT SER SPT 1
MARINE CORPS SYS CMD
2033 BARNETT AVE STE 315
QUANTICO VA 22134-5080

PROG MGR GROUND WEAPONS 1
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080
PROG MGR ENGR SYS 1
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080

CDR
MARINE CORPS SYS CMD
ATTN: SSE 1
2030 BARNETT AVE STE 315
QUANTICO VA 22134-5010

CDR
BLOUNT ISLAND CMD
ATTN: CODE 922/1 1
5880 CHANNEL VIEW BLVD
JACKSONVILLE FL 32226-3404

CDR
ATTN: CODE 837 1
814 RADFORD BLVD
ALBANY GA 31704-1128

CDR 1
2ND MARINE DIV
PSC BOX 20090
CAMP LEJEUNNE
NC 28542-0090

CDR 1
FMFPAC G4
BOX 64118
CAMP H M SMITH
HI 96861-4118

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ATTN: FUELS POLICY 1
1030 AIR FORCE PENTAGON
WASHINGTON DC 20330-1030

HQ USAF/LGTV
ATTN: VEH EQUIP/FACILITY 1
1030 AIR FORCE PENTAGON
WASHINGTON DC 20330-1030

SA ALC/SFT 1
1014 BILLY MITCHELL BLVD STE 1
KELLY AFB TX 78241-5603

SA ALC/LDPG
ATTN: D ELLIOTT 1
580 PERRIN BLDG 329
KELLY AFB TX 78241-6439

AIR FORCE WRIGHT LAB
ATTN: WL/POS 1
WL/POSF 1
1790 LOOP RD N
WRIGHT PATTERSON AFB
OH 45433-7103

AIR FORCE MEEP MGMT OFC 1
OL ZC AFMC LSO/LOT PM
201 BISCAYNE DR
BLDG 613 STE 2
ENGLIN AFB FL 32542-5303

WR ALC/LVRS 1
225 OCMULGEE CT
ROBINS AFB
GA 31098-1647

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CLEVELAND OH 44135

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BARTLESVILLE OK 74003

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ANN ARBOR MI 48105

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FAA
AWS 110 1
800 INDEPENDENCE AVE SW
WASHINGTON DC 20590